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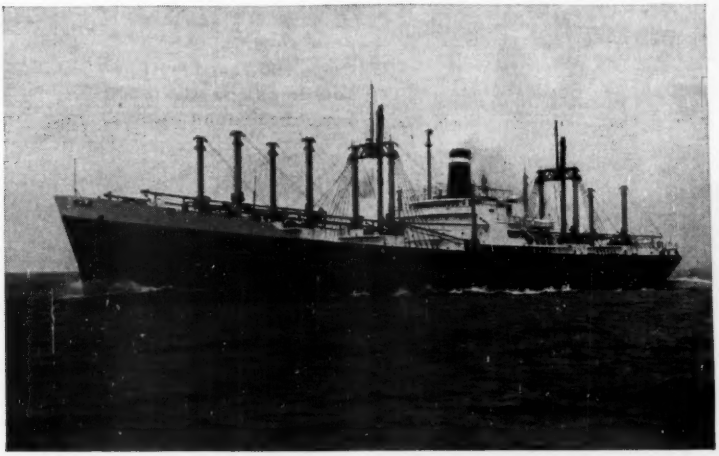

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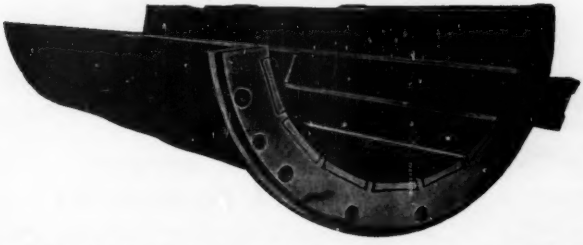

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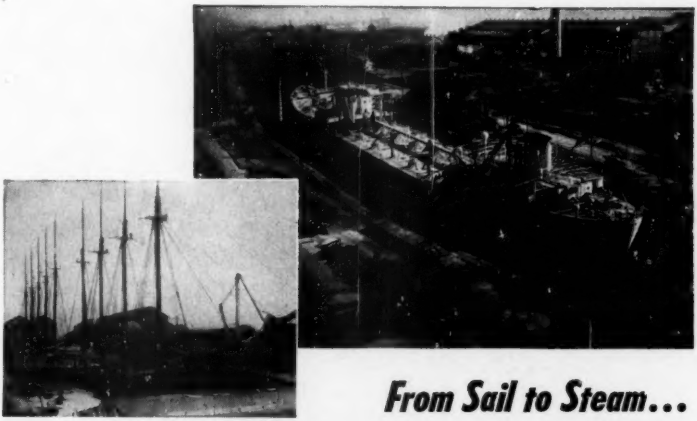

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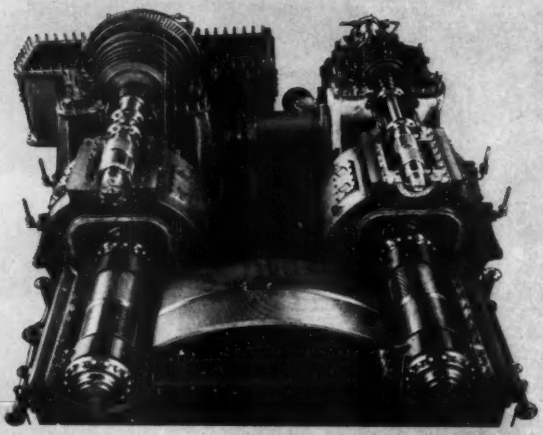

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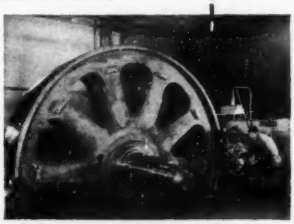

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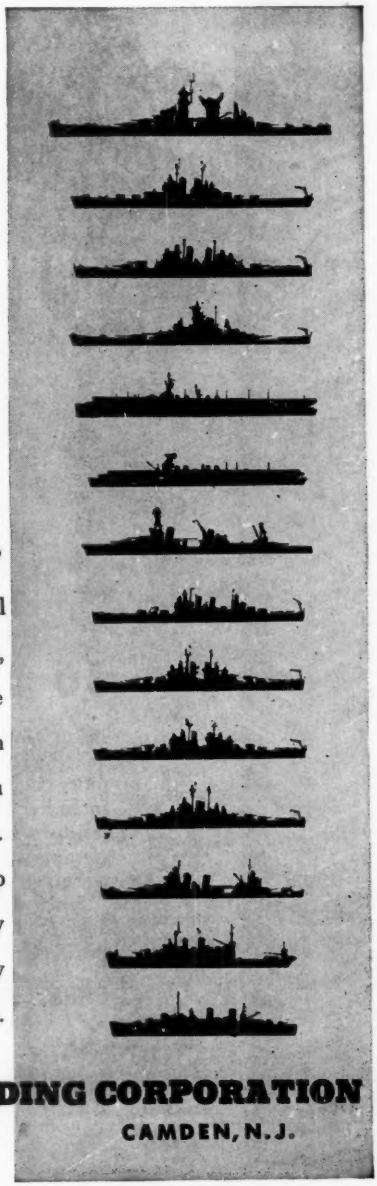

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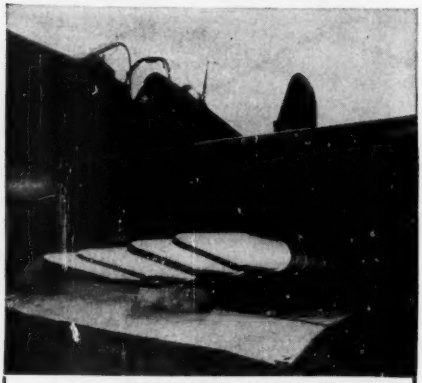

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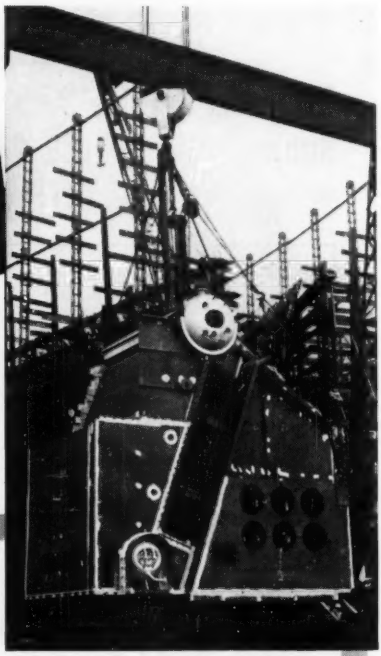

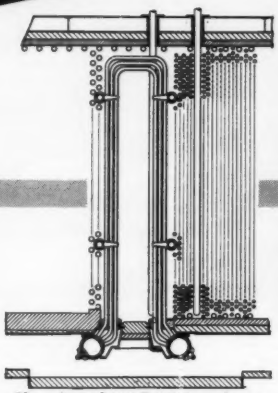

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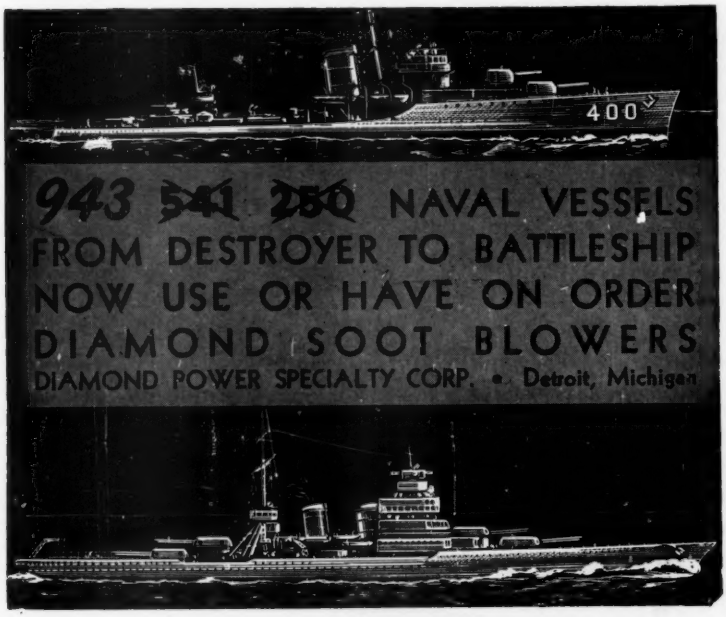
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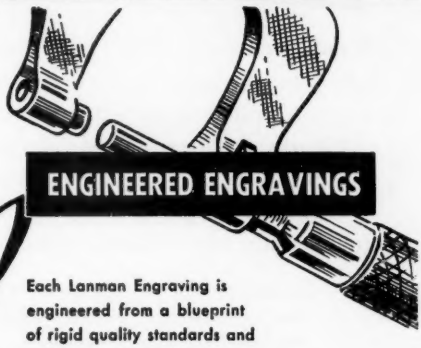

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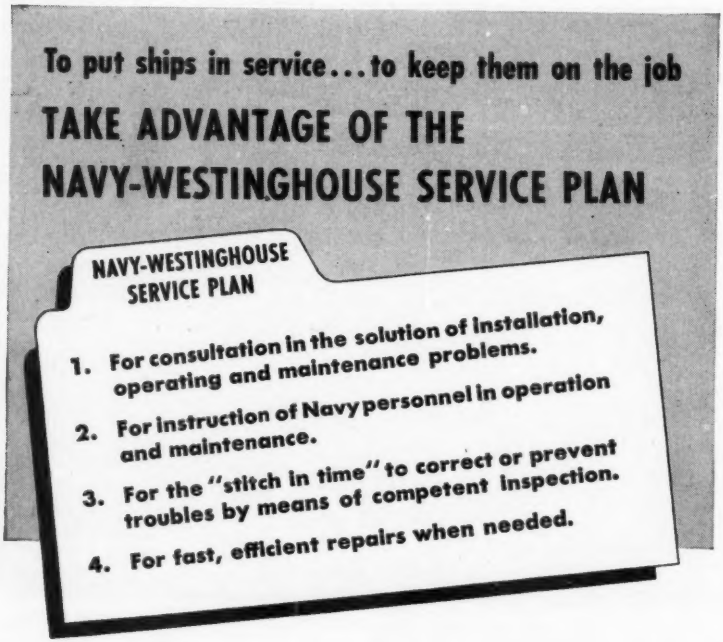
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THE ANNUAL BANQUET

of

THE SOCIETY OF NAVAL ENGINEERS

for 1953

will be held at the Hotel Statler

Washington, D. C.

on

FRIDAY, 1 MAY 1953

REAR ADMIRAL HOMER WALLIN, U.S.N., *President of the Society, will Preside.*

VICE ADMIRAL E. W. MILLS, U.S.N., *Retired, Past-President of the Society, will officiate as Toastmaster.*

MR. GWILYN A. PRICE, *President of Westinghouse Electric Corporation, will be the Speaker.*

REAR ADMIRAL HOMER N. WALLIN, U. S. NAVY

PRESIDENT, 1953

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JOURNAL
OF
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The Society as a body is not responsible for statements made by individual members

COUNCIL OF THE SOCIETY

(Under whose supervision this number is published).

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MR. J. J. KENNEDY

Captain J. E. HAMILTON, U.S.N., (Ret.), Secretary-Treasurer

SECRETARY'S NOTES

This issue begins the 65th year of continuous publication of the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS. The aim of the Council is to continue to maintain the high standards which were set originally in 1889 by the first Secretary-Treasurer Past Assistant Engineer (later Rear Admiral and Chief of the Bureau of Engineering) R. S. Griffin, U. S. Navy.

1952 ELECTION OF OFFICERS

As the result of the 1952 election of officers for 1953 and of Members of the Council for 1953 and 1954 as votes were finally tabulated.

The President of the Society for 1953 will be

REAR ADMIRAL HOMER N. WALLIN, U. S. Navy.

Admiral Wallin is serving as Chief of the Bureau of Ships. He succeeds Rear Admiral T. C. Lonnquest, U. S. Navy, who has served as President during 1952.

CAPTAIN J. E. HAMILTON, U.S.N. Retired, was re-elected to serve as Secretary-Treasurer. By action of the Council CAPTAIN R. B. MADDEN, U.S.N. and MR. A. G. FESSENDEN will continue as Assistant Secretary-Treasurer and clerk of the Society, respectively.

The following were elected to serve as Members of the Council during 1953 and 1954.

Regular Navy Members

REAR ADMIRAL E. W. SYLVESTER, U. S. Navy.

CAPTAIN P. W. SNYDER, U. S. Navy.

Naval Reserve Member

CAPTAIN R. E. W. HARRISON, U.S.N.

Civilian Member

MR. H. E. CARLETON.

The retiring members of the Council whose terms expired on 31 December 1952 are:

CAPTAIN W. A. DOLAN, JR., U. S. Navy.

MR. JOHN C. NIEDERMAIR.

CAPTAIN F. W. WALTON, U.S.N.

CAPTAIN F. C. WIESNER, U.S.N.R.

1953 ANNUAL BANQUET

The Annual Banquet of the Society will be held at the Hotel Statler, Washington, D. C., on Friday, 1 May 1953.

Official notices with application blanks will be mailed to all members early in March. It is sincerely hoped that all who are interested read and comply with the instructions which will accompany the notice. The growing popularity of this banquet indicates that the maximum capacity which was almost filled last year will be reached in 1953. Fire regulations will require some rearrangement. This may result in a reduced capacity for 1953. All of the tables will not be as desirable as some and *the tables will be assigned in order of receipt of application after* 15 March 1953. Only applications which are received in correct form will be considered.

The speaker for the Banquet will be:

MR. GWILYN A. PRICE

President, Westinghouse Electric Corporation.

VICE ADMIRAL E. W. MILLS, U.S.N., Retired, Past-President of the Society, will act as Toastmaster. The President, REAR ADMIRAL HOMER N. WALLIN, U. S. Navy, will preside.

LETTER FROM A MEMBER

The following interesting letter has been received from Mr. Milo C. Caughrean:

415 Jones Street
San Francisco, California
14 November 1952

"The American Society of Naval Engineers, Inc.
605 F Street, N. W.
Washington 4, D. C.

Dear Captain J. E. Hamilton, U.S.N.R.:

On page 457 of the August 1952 issue of your JOURNAL, I noticed your invitation for comments of disagreements by disputants. Therefore I would like to take exception to some of the statements made by Comdr. Arthur C. Smith, on page 486 of your August 1952 issue of the JOURNAL.

Comdr. Smith states that "The Idea Man is a Rare Bird." But after Comdr. Smith got through juggling this rare bird around, trying to fit him into some position of Rank, most of the Rare Birds, I'm quite sure, must have lost patience and quite a a few feathers, due to such treatment.

Having spent a great many years as a Merchant Marine Engineering Officer, and having been considered as an "Idea Man of Record," I realize the many problems that the "Idea Man" is confronted with. Also, the man Comdr. Smith is talking about is usually an independent thinker and cares very little about regimentation. Paradoxically the cold statistics show that it is the man of the Street who produces the greater number of Ideas which will later be developed and patented.

The importance or necessity of the Idea Man is not in any way to be mitigated. The peoples' existence and progress on this World has been made possible by the products of the Idea Man. There has never been a scarcity of Idea Men or the people of this Nation would not now be considered the foremost Nation of the World. The Idea Man is not a *know* everything or *do* everything Man. He is only a necessary tooth in the gears of this world of civilization. Neither is the Idea Man to be exalted, pampered, degraded or condemned in any manner that is not fitted to the case.

The non-believers are always present today as of yesterday. To cite a case, we are so used to condensing the spent steam from our Steam Engines into water in order that the water can be returned to the boiler, that we think there is no other way to do such an operation. It is possible to return spent steam to its boiler. The increase in boiler efficiency would be about 100 per cent and save us billions of dollars in fuel each year. I will be greatly surprised if the non-believers are not overwhelmed by the above statement. But critics are very apt at eating their own words.

Why don't the Powers that be do something to foster the use of the Idea Man rather than have those who are incapable of evaluating the Idea Man give him a fictitious title or a serfdom rating? Eli Whitney once said, "Depend upon the subtleties of the laws to defend the thieves." The Powers that be and the evaluators will use all the extremes to sustain their disputations.

Yours truly,

MILO C. CAUGHREAN"

JOINT COUNCIL MEETING

As has been the custom for several years, a meeting of the 1952 and 1953 Councils was held on 13 January 1953. At that time the outgoing president, Rear Admiral T. C. Lonnquest, U.S.N., turned over the reins to his successor, Rear Admiral H. N. Wallin, U.S.N.

At the joint meeting a well-deserved tribute was rendered to the Clerk of the Society, Mr. Arthur G. Fessenden, who is now in his 45th year of continuous loyal service to the Society. This was evidenced by the presentation of a check for $1,000.00 and a certificate which will be described in a later issue of the JOURNAL.

OUR PRINTER

It is of interest that we are now starting the 65th year of continuous publication of the JOURNAL. The printing is still being done by the printing firm which turned out Volume I, the printing firm of R. Beresford, which was established in 1867 as one of the earliest such commercial enterprises in Washington, is now managed by the second generation which in itself is an unusual record for an 86 year life. Our printer is now Miss Elizabeth Beresford, who has managed R. Beresford, Printer, since the death of its founder, her father.

THE FUTURE OF THE SOCIETY

From time to time, members of the Society have recommended that membership drives and advertising campaigns be conducted to lead to a bigger and better Society. Such things could be successful and would certainly lead to a BIGGER Society.

This matter was presented at the 13 January meeting for consideration of the Council. It is our opinion that the quality of the Society as judged by its membership, its banquet and its JOURNAL, the only outward manifestations, needs no violent improvement. There has been steady growth over the years and, at least, no decline in quality. This has been accomplished with a staff which has never exceeded three persons. Any enlargement would require a much grander office and staff which may be unnecessary and unjustified.

This note is published for the sole purpose of arousing the comment, pro or con, of members. Any clamor brought forth will be heeded and indicated action will be taken as rapidly as is practicable.

TRANSLATED ARTICLE

On page 118 is printed a translation of a Russian article which lays claim to much of the work which has been done on Wave Resistance. This translation is NOT published as a contribution to the dissemination of alien propaganda. Nor is it published with any intent to support the claims or contentions of the author. Any discussion which is forthcoming will be welcomed.

SOCIETY FINANCES

The Financial Statement for 1952 is published on page 214. Under the leadership of Admiral Lonnquest, and through Mr. Fessenden's extraordinary effort, the accounts are now ready for audit several months earlier than has been the practice.

JOINT MEETING OF 1952-1953 COUNCILS — 13 JANUARY, 1953

Seated (Left to Right): Mr. Arthur G. Fessenden, Clerk; Captain F. C. Wiesner, U.S.N.R., 1951-52 Council; Rear Admiral T. C. Lonnquest, U.S.N., 1952 President; Rear Admiral Homer N. Wallin, U.S.N., 1953 President; Captain F. W. Walton, U.S.N., 1951-52 Council; Captain W. A. Dolan, U.S.N., 1951-52 Council. *Standing* (Left to Right): Commander E. C. Thompson, Jr., U.S.C.G., 1952-53 Council; Captain R. E. W. Harrison, U.S.N.R., 1953-54 Council; Captain C. G. Grimes, 1952-53 Council; Rear Admiral R. E. McShane, U.S.N., 1952-53 Council; Commander R. Gerber, U.S.N., Chairman of Ballot Counting Committee; Captain J. E. Hamilton, U.S.N., Ret., Secretary-Treasurer; Captain P. W. Snyder, U.S.N., 1953-54 Council; Rear Admiral E. W. Sylvester, U.S.N., 1953-54 Council; Captain R. B. Madden, U.S.N., Assistant Secretary-Treasurer; Mr. H. E. Carleton, 1953-54 Council. *Absent:* Captain Charles Bittinger, U.S.N.R., 1952-53 Council; Mr. J. J. Kennedy, 1952-53 Council; Mr. John C. Niedermair, 1951-52 Council.

OFFICER-CIVILIAN RELATIONSHIPS IN SEMI-MILITARY TECHNICAL ORGANIZATIONS

J. K. FORDYCE

THE AUTHOR

was born in Oakland, California, in 1918. He received his A.B. (Political Science), at Stanford University, and a two-year graduate scholarship to Maxwell School of Citizenship and Public Affairs, Syracuse University, from whence he received M.P.A. (Public Administration). He has been employed by the Division of Testing of the Los Angeles City Civil Service Commission (test construction); and in job classification, training and employee relations work for the Navy Department. He is presently Deputy Director of the Civilian Personnel Division, Bureau of Ships, Navy Department.

He has received sundry training in the field of General Semantics and has been active in the formation and development of the Washington General Semantics Group. This paper is written from the point of view of this discipline.

I. INTRODUCTION

A considerable amount has been written about the organizational and social structure of purely military organizations. Much more has been said about non-military organizations and social groups. Very little has been written about organizations which are made up of both civilian and military personnel.

While very little has been written, a great deal has been spoken, most of it privately, by persons in such organizations. Such comments as have come to the writer's attention indicate some significant problem areas.

When one considers the number of persons employed today by the Department of Defense in mixed military-civilian organizations, the responsibilities imposed on these organizations, and the apparent number of unresolved problems and misunderstandings resulting from this particular organization type, it would seem to merit more positive effort than it has received.

The writer is no expert on this problem. It is doubtful that the subject has been explored deeply enough to provide us with any experts. It must be admitted, too, that his first-hand experience has been limited to the civilian side of the picture. It is hoped, therefore, that the comments that follow will be viewed more as questions than pronouncements. They are set down in the hope of helping to stimulate more open discussion and better solutions.

The military-civilian technical organization is an interesting challenge.

It brings together the diverse points of view of the operator, the generalist, and the technical specialist—potentially a highly desirable situation for the solution of complicated technical problems. It brings together, in close contact, persons who belong to the civilian and military groups, groups which for all they have in common, have generally had some lack of mutual confidence and esteem. (The same might be said of any number of other groups.)

No attempt is made in this paper to present any particular organizational arrangement as a panacea. The writer does not believe that any such panacea exists. He does believe, however, that it may be possible eventually to agree on a few simple principles which will lead to more satisfactory solutions. Above all, he believes that the commonly met fatalistic attitude, "Let's face it, this is it," is becoming increasingly out of date.

II. THE NATURE OF A "MILITARY-CIVILIAN TECHNICAL ORGANIZATION"

The term "military-civilian organization" is used here to designate any organization which is a part of the Department of Defense, staffed by both military and civilian personnel, including a substantial force of engineers or scientists, and primarily concerned with research for, design, testing, and/or maintenance of equipment for military use.

Such organizations have two key groups with which we are concerned. These are the officer group and the civilian engineering and scientific group. The primary and distinctive function of the officer group is presumably combat. However, with the increasing importance of the supporting and technological aspects of warfare, they have been more and more removed from this distinctive feature of their profession and more and more concerned with activities which slide smoothly and without sharp demarcation into activities traditionally considered civilian. There are social and political questions here with which this paper is not concerned: How far along the continuum from military to civilian function should activities of the military group extend and to what extent will they retain the traditional social status that apparently sprang originally largely from public esteem for the great hazards and responsibilities of the combatant officer? These questions are pertinent, but beyond the scope of this discussion. The question involved here is the efficiency (in a broad sense) of those engineering and scientific organizations in which military and civilian functions are being blended through the activities of military and civilian personnel.

In these organizations, the primary function of the officer is to serve as the responsible representative of the operating forces. This function includes two primary sub-functions; serving as a manager, and serving as a "consumer representative," i.e., injecting into the supporting technical organizations indispensable first-hand information as to the material needs of the forces in the field. In nearly all cases, officers have been given management responsibility for their particular military-civilian technical organization, at the bureau, field activity, or comparable level, and generally for much smaller organizational groupings. The primary function of the civilian group is to provide engineering and scientific experience. Both primary functions are found, in varying degrees, in both groups. The officer may be primarily an engineer, and the civilian primarily a manager.

The functions of the two groups are further differentiated by the frequent rotation of assignment of officer personnel and the stability of civilian assignments. Thus, the two groups are placed in the complementary positions

of "knowing less and less about more and more" and "more and more about less and less."

Broadly viewed this type of organization seems well suited to solving technical problems to meet operating needs. Its relative success supports such a conclusion. It carries with it, however, many problems, problems which are not unique to this organization form, for the most part, but which are frequently made more acute by it.

The more important of these problems are described below.

1. The mixture of personnel from two distinctly different types of career systems, with one group holding the key managerial positions, inevitably creates problems.

a. To begin with, it should not be expected that persons from career systems as different in outlook as these would seem to be would naturally and easily form a homogeneous group. Most persons who will be successful in a particular field come to that field with a certain set of predispositions and aptitudes. Further, in the pursuit of a particular career, a man's personality will be modified and tend to become uniform with those of his fellows, in accord with the common types of experiences they encounter in following that particular career. Merely placing a man in a different type of organization or social group will frequently produce marked changes in his behavior. For example, the mere act of placing a man in uniform, with all that implies to him, may change his outlook considerably.

The career system of the officer is, historically, an older form of social organization, in which the maintenance of a rigid structure of authority is necessarily a prime consideration. The individual entering such a system surrenders certain personal liberties, and in return he receives certain advantages. He becomes a member of a social system with relatively clearly defined roles, and with a relatively heavy emphasis on the prerogatives of status. He is rewarded by the prestige, diversity, training, glamour, security, etc., attendant to this career system. He is carefully indoctrinated in military tradition. This point needs no further elaboration. Such a career has evident significant differences from the typical civilian professional career, which occurs in a more democratic and individualistic environment.

b. It is significant that it is the personnel from the more authoritarian and status-conscious group who are in the top managerial positions, so that their perspective is most likely to permeate the organization. Since the civilian does not receive the benefit of being formally a member of this system, a source of friction exists. Further, there is a tendency to fit the civilian into the status system. The most general tendency seems to be to fit the civilian professional in between the commissioned and non-commissioned officer groups. While such attitudes may be unrecognized by their possessors, and even, apparently, in many instances by their recipients, there is evidence that they exist.

The writer does not mean to imply that authoritarian systems and status systems are *ipso facto* bad. They are obviously necessary and desirable, although possibly we may hope to outgrow the present profusion of unnecessary and undesirable forms in which they occur. The point is that the authority and status systems of the officer and the civilian scientist or engineer are different, and here they have been brought into conflict by their proximity. This is one of the several factors contributing to frustration and loss of dignity among civilians.

c. When two different groups with closely allied functions are working side by side in the same organization, it is almost inevitable that there will spring up between them competition for power, prestige, recognition, etc. Each group

will tend to become more cohesive to protect its benefits and seek other advantages. The strength of this largely unvoiced and frequently vaguely sensed conflict depends on the degree of satisfaction of the various members of the groups with their present position and opportunities and the apparent stability of the *status quo*. It is certain to exist to some degree under any circumstances.

d. Of the two groups, the officer group tends to be the more cohesive, because of its smaller size, the parallel backgrounds of its members, and their long established working relationships. Because of its larger size and the diversity of background and higher rate of turnover of its members, the civilian group usually is less cohesive, although its organizationally subordinate group usually might indicate a greater need for it to maintain a united front.

e. Because of the organizationally subordinate position of the civilian, who is, to a great extent, dependent on officer approval for his progress and promotions, he is not apt to voice officially his feelings on the subject of officer-civilian relations. In many instances, there even seems to be a strong tendency to bend over backwards to avoid offending the officer group. Many small signs can be found of practices instigated or perpetuated by civilians which are indicative of such a communication block. It is common practice, for example, in listing the names of persons attending a conference, to list the names of all officers, in order of descending rank, before listing the names of any civilians, regardless of rating.

f. One of the most serious consequences of this type of organization is that the existence of a separate managerial group restricts the opportunities for progress and advancement for the members of the primarily engineering and scientific group. As he advances up through the hierarchy, the civilian eventually reaches a point where he finds his further progress barred by an officer. The officer may be acting as a manager and "consumer representative," or, because of his frequently excellent technical background, as an engineer or scientist. The civilian must either accept this situation or leave. Or, seeing the handwriting on the wall, he may have left at some earlier stage in his progress. With the top jobs ruled out of competition, it must be expected that the calibre of intermediate and lower levels will suffer.

This condition is made worse by the tendency of the managerial (officer) group to keep in its hands the formal and real authority. For example, it is customary to have the correspondence and reports signed by officers. Such policies have three serious effects. Firstly, lack of authority and the symbols of authority is a constant irritant to the civilian group. Secondly, the top managerial group is apt to be overloaded because adequate delegation of responsibility is not felt to be appropriate or is not feasible. Thirdly, and most important, the lack of responsibility removes an important stimulus to individual development and growth.

g. Because of the superior position and cohesiveness of the officer group, and the different stages of development of the officer, versus the civil service career systems, the officer generally has more opportunity for personal development. More attention is given to the career development and training of the officer. The idea of professional development through rotating assignments, college training, etc., permeates the thinking about the officer career systems. The needs for immediate production are more apt to dominate the civilian career. This is one of the reasons why the officer group is more apt to develop individuals who are qualified for the top level and managerial positions, and this, in turn, is one of the reasons for a tendency to expand the control and activities of the officer group, even into occupational areas which are custom-

arily considered "civilian," where the apparent need for "consumer representation" is slight. This, then, tends to create further problems with respect to the civilian working force.

2. An organization made up of a rotating group of managers and a fixed group of specialists has serious problems as well as blessings.

a. A person who is moved from one important managerial position to another at intervals not generally more than four years and usually less must be a person of considerable ability and restraint to be a success. While his general background may be excellent, making him better qualified in this respect than his specialist subordinate, his specific knowledge of the organization and specialty into which he has stepped is ordinarily less than theirs. The learning time for him to accumulate the knowledge necessary to make him a truly competent manager of his new organization may well be one to two years. For some time, therefore, he is in grave danger of hindering the work, irritating his subordinates, and exposing his ignorance by making judgments and decisions which he is not at that point qualified to make. Equally serious, he may be afraid to take action or rely on a staff with which he is not well acquainted, so that the program may go into low gear and lose continuity and momentum. The forbearance, willingness to rely on subordinates (and risk a few black marks in the process) and insight required to make a success of this form of tight-rope walking, without a few bad spills, are not commonly found.

b. Another occupational hazard of the rotating manager is that he may fail to develop an adequate sense of long range responsibility for the organization to which he is attached for such a short time. He may be inclined to make decisions which are expedient for his tenure but are unsound in the long run.

3. The existence in one organization of two groups of personnel with overlapping assignments and capabilities makes it possible to compensate for or cover up weaknesses in performance in one group by using personnel from the other group. Accountability for performance is apt to be missing. The usual situation is to compensate for weaknesses in the civilian group by using officer personnel. As a temporary, emergency expedient, this provides a handy and useful solution. However, if, as very frequently happens, it becomes a permanent means for avoiding the difficult and unpleasant task of correcting the basic problem, it encourages weakness in the civilian staff. Two common attitudes found in officers tend to impede more positive action. One attitude is an unwillingness to "meddle" in the civilian chain of command, not only because it may be difficult and unpleasant, but also because the officer feels like an outsider. The task of developing a strong civilian staff is frequently an unassigned responsibility, with no one carrying the ball. The other attitude is a tendency for officers to set lower standards of performance for civilians than they do for officers. This may represent the easy way out, and, also, a point of view which is a corollary of the civilian's position in the status system.

4. Managers do not spring full blown upon the scene. What, then, is to be done with the embryo managers in this type of organization? In the ordinary industrial organization, they may be formally assigned to any part of the organization, fitted in as a regular part, except that special attention is given to their progress and training. The difficulty that is encountered in the semi-military organization is that it is customary not to have officers supervised by civilians. Various solutions are found to this problem. Nearly all of them have serious drawbacks, the most general of which is that they seem to carry out in

fact the idea that the civilian is an "inferior." Aside from this general problem, the most serious hazard is that a young and inexperienced officer may be named as supervisor over a more experienced and competent civilian. Other typical solutions with obvious disadvantages are the establishment of dual chains of command, one officer and one civilian, and the placement of the junior officers in "staff" positions, the relationship to the civilian group being vague and ambiguous, usually encouraging a lack of accountability.

5. All of these factors make it difficult to recruit, develop and retain a competent civilian engineering and scientific staff.

6. To summarize: The military-civilian technical organization is faced with inherent problems which may, depending on how they are handled in particular situations, have a serious effect on the efficiency of the organization. The efficiency of the officer corps is not apt to be seriously affected, but the efficiency of the civilian corps will suffer, in greater or lesser degree. Strong undercurrents of antagonism may develop. The officer is faced with an extremely difficult problem in adapting himself rapidly to new situations. And, finally, his indoctrination and training do not, for the most part, fit him to manage a civilian group.

These statements are misleading in that they are only statements of averages, and, equally important, are only *some* of the factors involved. For example, one can not conclude that the civilian staffs of such organizations are necessarily inferior. Too many of the variables have not been mentioned in this discussion. There is no doubt that in some instances superior civilian staffs have been developed, and that, in any such organization, many persons of superior ability will be found. One important factor, for example, with a strong positive effect, is the inherent interest of many of the civilian jobs, and the facilities and money available for carrying out these jobs. One must be careful, too, about generalizing concerning the officer personnel or the "officer point of view." One can not help but be impressed not only by the technical competence but also by the broad gauge of the officers one generally finds in key positions. In many or most instances, their understanding and appreciation of progressive management techniques and philosophy will match that of the best industrial leaders, current legends concerning "brass hats" notwithstanding.

But regardless of how high the current levels of efficiency may be, the question, "can they be improved," remains, and we are inquiring into one phase of that question.

III. SOME IMPORTANT DEVIATIONS AND TRENDS

These statements on the problems of military-civilian technical organizations are intended only as guides to the usual problem areas, the existence and importance of which must be assessed for each such organization. When we start looking at actual organizations, the deviations will frequently be found to be very great. In general, the management and technical control of officer personnel decreases in accordance with the technological distance from the consumer. Thus, the degree of detailed control by officers in a government laboratory primarily concerned with research underlying new equipments is much less than in an office primarily concerned with the evaluation of the military performance of existing equipment and the determination of need for new equipments capable of performing particular tasks. In some laboratories, there may be no more than one officer, at the very top, in a position involving

technical control. Other officers attached to the organization may be placed in staff positions outside the civilian chain of command. This type of situation is, of course, in accord with the general rationale of the military-civilian organization. Research is more purely technical and there is, therefore, less need for the "consumer representative."

Even within any one organization, however, great differences are found, depending on the personalities involved, area of work, relative abilities, etc. In some cases, officers are supervised by civilians. In many cases, civilians sign correspondence. In some cases, distinctions between the groups are all but eliminated. In others, all significant authority will be retained by the officers, and the civilian may be treated as if he were a "second class citizen." Each officer and each civilian has a slightly different slant and each may have his own solution to the problem of officer-civilian relations. Testimony to the individual differences found are the amazing variety of organizational relationships, a variety of forms of staff organizations (if they are civilian, generally possessing very little authority, and if they are officer, generally possessing considerable authority), etc. One commonly found device is the establishment of organizational patterns, titles, and apparent authorities which appear to give more authority to the civilian staff than is actually found in practice. This may be done to raise their grade levels, and, thus, rate of pay, and/or to bestow upon them the symbols of authority, with the hope that this will raise their morale. Such actions are likely to have a degrading effect on the civilian staff. If they perceive the hollowness of the gesture, they may resent it. In any event, such rewards bestowed without requiring a commensurate return in terms of the shouldering of responsibility will tend to develop a compliant rather than a strong staff. Vague authorities and organizational relationships are, of course, also inimical to the development of a strong staff.

The situation is not only varied, it is also changing, and some of the trends are important. The most significant basic change is that the organizations which prepare us for war are becoming larger, increasingly technical, and increasingly interwoven with the remainder of the nation's economy. The Department of Defense is Big Science, Big Technology, and Big Business. Military skills and military perspective are no longer adequate to make a good officer. His training is becoming increasingly broad and his contacts increasingly varied. He may be sent to graduate schools of business. He may serve an internship in industry. He may study with the "long hairs." He may become a military-business specialist, a personnel specialist, a nuclear physicist. He is becoming more civilian. And so the two groups are becoming more homogeneous, although they are also being thrown more into competition for the same jobs.

At the same time, the increasingly specialized nature of the job, and its huge size, makes it necessary to depend increasingly on civilian experts. And the bargaining power of this group is increased by the nation-wide shortage of such experts.

Finally, the trend toward greater democracy throughout our entire business life is also very much in evidence in the Department of Defense.

In general, the problems mentioned seem to be slowly being solved, although in some instances they may be more keenly felt because of the greater pressure to solve them.

IV. AN APPROACH TO THE PROBLEM OF OFFICER-CIVILIAN RELATIONSHIPS

It is obvious that the problems cited above are not isolated ones, susceptible to individual analysis and eradication by order. They comprise a complex interweaving, a self-generating milieu. For example, if the nature of military control in a particular organization has failed to develop a strong civilian staff, the nature of the civilian staff makes it necessary to continue such control. It appears to the writer that the principal problem is one of attitudes, and these are not to be changed overnight or by gross action. Organizational attitudes are not easily changed; they perpetuate themselves.

It has been the writer's experience that solutions to the problems presented are frequently forestalled by one or both of two arguments.

The first is the argument that if the civilian force of these organizations has suffered under the current arrangements, it is because they have not competed successfully for positions of more authority; they have been more interested in security, stability, seniority, and a comfortable income. According to this point of view, if they aren't happy with the present situation, it is incumbent upon them to initiate improvements within their own group. The writer does not contest the desirability of this or any group attending to the improvement of its performance. However, top management must inevitably assume the responsibility for the output of their organizations. If this can be improved by improving the motivation, capacity and initiative of the civilian staff, it is a problem for top management. In the opinion of the writer, however, it will be well nigh impossible to make really substantial advances in this direction without making substantial progress on some of the problems discussed here.

It is customary to throw much of the blame for this problem on to the Civil Service system itself. There is no doubt that it can stand a great deal of improvement. Further, there is no doubt that the Department of Defense could exert a tremendous pressure toward achieving some of these improvements. In fact, however, there are very few organizations which have more than scratched the surface of what can be done *within* the Civil Service system. Perhaps we should first apply more time and ingenuity in this area.

The second argument which frequently befogs the issue is the debate as to whether these organizations are "military" or "civilian." If they are "military," then "military control" is justified, or if they are "civilian," "civilian control." What do "military," "civilian," "military control," "civilian control" mean? We rapidly find ourselves in a semantic muddle. Ordinarily, they mean whatever the protagonist is trying to prove.

This is a *secondary* and *unnecessary* argument. The real issue with which we are concerned is the problem of determining the organizational and administrative arrangements which will best help these organizations to accomplish their mission. We can measure proposals against this standard without involving ourselves in these questions of definition.

It is the purpose of this paper to raise the question as to whether there do not exist a few principles which can be agreed upon, and which will constitute a reasonably complete frame of reference for the solution of the problems discussed. Such a frame of reference, if practicable, should have the value of encouraging a common point of view which is now lacking between the military and civilian groups.

1. *Division of responsibility:* Since the problems we are concerned with are largely the result of mixing of two dif-

ferent career groups, with different points of view, in one organization, the most obvious question is whether we should not eliminate one or another of these groups, making at least the engineering and scientific and management staff either entirely military or entirely civilian.

If we eliminate the civilian part of the organization, the officers would then have to fill the specialist positions as well as the managerial and consumer representative positions. This would require some modification of the officer career systems. Such a modification should be feasible. However, we would be faced with another problem which might well be more serious. Successful scientific effort carries with it increasingly the implication of democratic relations between the persons engaged in this effort. To put it another way, the idea must have more importance than the individual, since the correctness and significance of the idea is the primary determinant of success. In the purely military situation, coordinated and prompt action must take precedence. A rigid hierarchal status system is well suited to the latter but not to the former. It is frequently simple to predict the decision in the case of a disagreement between two officers, not on the basis of the relative merits of the ideas or even on the basis of their organizational positions, but rather on the basis of their rank or relative seniority. Issues are frequently not fully debated because it is not prudent to disagree strongly with a senior. There is a stronger assumption in this system that the senior is right than is customarily found in the business world and particularly in a civilian scientific organization, where the individual's scientific upbringing has trained him to question and discuss problems and answers as such, without such deference to status. While the trend is toward greater democracy among the officers engaged in the less military functions, this still remains an important problem to be faced if officers are to take over more and more of the primarily engineering and scientific work.

There is another outgrowth of the military career systems with equally severe effects. This is the frequently found tendency of officers to avoid "sticking their necks out," because one is more apt to be held accountable for something done wrong than for an opportunity missed.

If we eliminate the officer part of the organization, the civilians would have to take over the managerial and consumer representative functions. Such an organization, would, of course, more nearly parallel the typical industrial or governmental civilian technical organization. Outstanding examples can be found in both cases of the satisfactory solution of the problem of developing an adequate managerial group and adequate consumer representation. It is frequently said that it is not practical to make a shift toward civilian control because it is impossible to develop a group of adequate ability under the Civil Service system. There is not room here to debate this issue at length, but there are enough examples of civilian government organizations which have developed outstanding proficiency to justify taking issue with this assumption. Such organizations have not only developed a high degree of management competence but have also solved extremely complex problems of public and consumer relations, in a much more difficult political setting.

A related problem is that of finding managerial aptitude among the civilian engineering group. From observation, it appears that such aptitude is more frequently found in the officer group, due probably partially to their training and partially to the fact that the officer career is more apt to attract persons who are ambitious to be "in charge." This is a difficult but not insurmountable problem.

An objection that will certainly be raised to this proposal is that an all-civilian organization would not be sufficiently understanding of and responsive to military needs. Actually, the popular idea of the "taut ship" type of military organization seems to be largely a myth in these military-civilian organizations. Many civilians coming into this type of organization for the first time are surprised at the frequent looseness of hierarchal controls, and lack of accountability. (Although when clear controls exist, there is a high degree of compliance.) There seems little reason to believe that a well-run civilian organization is any less responsive. Securing an understanding of military needs would certainly require a much more intensive indoctrination of civilians, particularly field and operational indoctrination. There should be no problem of developing an adequate sense of loyalty if the feeling of being second-class members of the military departments can be eliminated.

This discussion of purely military or purely civilian organizations is, of course, theoretical. It has been included for what additional perspective it can give us for viewing the mixed type of organization that we have and will have for the foreseeable future. The writer is not convinced but what this is a desirable situation. If we can make such organizations work at a high level of efficiency, it gives us the important advantage of being able to bring to bear on our problems diverse points of view.

If we are to get the most from this situation, the civilian should be expected to concentrate on contributing those qualifications which are most purely civilian—specialized scientific and engineering knowledge. In turn, the officer should be expected to concentrate on contributing his military skills and knowledges—primarily his knowledge of operating problems and needs.

How are we to divide responsibilities between the two groups?

One thing we must recognize. If we set cut-off points, on the organization ladder, by law, directive, or practice, so that it is known or appears that the members of one group may not expect to hold positions above those points, then by that much, and more, we destroy our ability to develop a competent group. The nearer the bottom the cut-off points occur, the *progressively* more difficult it becomes to develop and maintain an adequate staff of professional personnel, because of the lack of opportunity and the lack of responsibility. The same thing is not true in reverse. As long as the top positions are the incentive, a vigorous and competent group of managers can be developed even though they do not monopolize the intermediate positions.

Many persons have suggested that we can make the best use of civilian and military qualifications by building the engineering and scientific functions around a purely civilian chain of command. Officers attached to this organization would be in an advisory capacity as "consumer representatives." Presumably they would be fresh from operational assignments. This proposal has the values of keeping the two groups "out of each other's hair" and providing a long enough civilian chain of command to encourage the development of a qualified civilian staff. It is actually in operation at some laboratories.

While this type of organization may be a desirable objective, it does not appear to be practical at the present time, in most instances. Such an organizational arrangement would result in wasting the engineering, scientific, and administrative talents of many highly trained officers. It would also create the difficult problem of finding adequate civilian replacements for them.

Summary: Conceivable divisions of responsibility cover a wide range. The mixed military-civilian organization is potentially the best because of the different points of view it may bring to bear

on a problem. To get the most out of this organization, officers should be most concerned with contributing the military, operational point of view, and civilians the engineering and scientific point of view. If there are cut-off points in the organization above which members of one group may not rise, they should be placed as high as possible in order to establish the maximum incentive for both groups.

There are practical limitations at present on how far we can go in this direction. How can we start?

2. *The principle of selecting the best man for the job:* Few principles of administration are more important or more widely accepted, at least in theory, than the principle of putting the best qualified man in the job. Let us see what implications it has for the problem of officer-civilian relations.

To begin with, although in practice this principle is frequently ignored in favor of seniority or other circumstances, it is generally recognized by employees (at least the best ones) as a good and fair one. It is unquestionably a strong stimulus to good men in the organization to see that their opportunities in the organization are limited only by their ability to produce. It is the strongest stimulus that the average organization has at its command.

On the average, the qualifications of members of the officer group for the higher level positions are superior to those of the civilians. Many of the reasons for this have been given previously. On this basis it may be possible to justify the current placement practices, *on the average.*

The obvious point is that we are not placing averages, but individuals. The better people, at least, want to be treated as individuals, on the basis of their own merits, and not as averages. For individual cases, the average is an artificial measure which may be quite inaccurate. The talented civilian engineer with the qualification or potential qualifications to fill a job customarily held by an officer can not easily stomach the idea of being placed in a subordinate position simply because he is a civilian. It is hard to imagine a depressant with a more debilitating effect. This influence seems to reach the great majority of civilians who work in the system, whether or not they are in direct contact with it. One might say that it is in the atmosphere, and like the atmosphere, it is frequently not noticed by the people who breathe it. It does no good to say that if they were not prepared to accept this situation, they should not have come to work for this type of organization. This does not excuse the organization from the obligation of developing the best possible staff to turn out the best possible product.

Superficially, it might appear that the full application of the principle of placing the best qualified man in the job would result in a considerable upset and shifting around in the military-civilian organization. On closer investigation, however, this does not seem to be true. Any realistic application of the principle requires that all qualifications be taken into account. This would include, for example, the simple fact that a man wears a uniform. Taking nothing else into account, this will tend to qualify a man for some jobs and disqualify him for others. For example, there are some public relations jobs where the wearing of a uniform should be an advantage. There are others, where people may be allergic to "brass," where it may be a disadvantage. With the current mores of the officer group, and others, there may be a feeling that one is not dealing with an "official" representative unless one is dealing with an officer. On the other hand, it may be claimed that a civilian with authority has an advantage in dealing with an officer of high rank because he has no comparative rank which may put him at a disadvantage, military convention being what it is.

These remarks merely indicate that, while no possible qualifying factor should be left out of account, general rules, which are statements of averages, are not adequate for the complex conditions that exist. The military group seems to attach more importance to the uniform (officer status) as a qualifying factor than is justified from the point of view of qualifications. This is unfortunate because this factor by itself is basically an artificial one.

A related factor, generally considered quite important by the military group, is the disciplinary or control system of which the individual is a part. There is a belief that the military chain of command should be retained intact in order to insure the necessary responsiveness, so that no one but an officer is qualified to occupy a position in this chain of command. Some comments have already been made on the not unusual degree of control and responsiveness of the military chain of command in these organizations. There seems to be no significant reason why a mixed chain of command can not be just as responsive. Poor performance can be just as damaging to a civilian career as to a military career. If a civilian can get by with poor performance without jeopardizing his promotional opportunities or even his retention in his present assignment, this is more an indictment of management than of the Civil Service system. There is no doubt, however, that the supervision of civilians is more difficult because the system is less impersonal and authoritative.

"Responsiveness" as used here is not intended to mean compliance because of a formal authority relationship alone. This is more apt to be found in the officer group. As indicated above, it may be carried to the point of being a weakness in this type of organization. The writer means to imply more give and take as a valuable part of the relationship.

By the recognized conditions of their career, officers are more amenable to changing and emergency assignments. This will tend to make them better qualified for some assignments. There is apparently less need for the person specializing in primarily civilian areas to change assignments. However, if civilians want to qualify themselves for some of the higher level positions in which broad background is an important qualifying factor, they will have to accept greater mobility as a condition of their careers.

Another, related, qualifying factor is that of individual loyalty and responsiveness. With his broader and more thorough indoctrination and more definite career interest in the organization, the officer may be better qualified for responsible positions, particularly when responsiveness to and understanding of operating needs are paramount considerations. This could probably be easily corrected if the civilian were more a member of the team and less a hired hand.

A part of the mythology of the military officer group that aggravates this problem is what seems to be a doctrine that the officer is competent to command any job. It is true that any intelligent person with some managerial talent can get along in an extraordinary variety of positions. But if there are available elsewhere or, particularly, working for him, persons who are better qualified than he, the organization pays a high price. There are far cheaper and just as effective means of training.

Some consideration of the general statements made in the earlier part of this paper indicate that, by and large, one would expect to find that the officers are better qualified for the positions they now hold. This seems to be true, but the situation may be changed merely by changing our objectives and methods.

The fact that no extreme changes would be brought about by the adoption

of this principle in the short run (there would probably be marked changes in the long run), is not, however, the important point. The significant problem at present is the usual arbitrary and absolute nature of the dividing line between the two groups, placing all members of one group, regardless of their qualifications, in an inferior position.

The situation is epitomized by the following statement in a current training manual for Naval Officers: "In a sense, an officer of the lowest rank has authority over the highest rated civilian." *

Exactly what the writer had in mind, we do not know. In its ambiguity, the statement is typical of the common statements one hears about this problem. Whatever the meaning, its effect on a civilian professional is obvious. It is antithetical to the individual consideration and treatment inherent in "placing the best man in the job."

The simple facts of the case are that under the uniform or the mufti are individuals of widely varying qualifications, with significant overlaps between the two groups. The officer may have superior technical qualifications to the civilians in the group in which he is working. The civilian may be a superior "consumer representative" to the officers working in his group. Engineers, reservists, "regulars," businessmen, lawyers, former enlisted men, etc., may be found in either group. And the components of each job to be done are different. Managerial talent, operating experience, scientific knowledge, or other may be paramount in a particular job. To say that management jobs should be reserved for officers, or that technical jobs should be reserved for civilians is proximate to saying that A plus B equals 10, when we don't know the value of A or B. It may be that a specific A. say Cdr. Jones, is the best qualified for a specific B, say head engineer on anchor design. And Mr. Smith may be best qualified to head up procurement for Bureau B. When we are faced with a specific placement problem, the general rules may not apply, unless we adopt a rule that takes into account individual differences.

The qualifying or disqualifying aspects or civilian status are not as absolute as they are generally treated.

3. *The principle of equivalent opportunity:* This principle is a necessary corollary to the approaches discussed above. According to this principle, each man should have an equally good opportunity to develop, produce, and receive recognition along the lines of his interests in so far as these are compatible with the objectives of the organization and his professional field.

What interests are compatible with the objectives of the organization and these professional fields? According to the above discussion, the primary career opportunities of the officer should be in that area which stretches from the purely military to the twilight zone of military-civilian. This is particularly military operations and management. Similarly, the civilian professional should find his opportunities in the area extending from the purely civilian to the same twilight zone—including engineering and scientific activities and management. Most of the top jobs—the ones providing the maximum incentive—fall in the twilight zone. Similarly, areas such as logistics may be suitable to either.

It is not desirable to exclude either group from the other's field entirely. The "consumer representative" needs some technical understanding of what is practicable; the civilian technician needs some understanding of operating problems. In addition, the officer-scientist and the civilian engineer-officer may

* "The Radar Supply Office—Authority Over Civilians," *Functions of the Naval Administrator*, Bureau of Naval Personnel.

both be able to contribute talents that would otherwise not be obtainable.

This is an objective. It will not be practicable in many instances until the opportunities, incentives and requirements for the civilian are equivalent to those for the officer and the results have been obtained.

V. SUMMARY

It is the opinion of the writer that we shall not have maximized the usefulness of the military-civilian organization until we have created equal status for the civilian and military groups, granted them equivalent opportunities for development and recognition and granted the favors which may be bestowed by the organization on the basis of individual qualifications.

A highly placed scientist-officer commented recently that we have provided amply for the dignity of the officers; we must do the same for the civilians. This is good business as well as good human value. Many persons apparently feel that this can best be done by maintaining to the utmost the integrity of the chain of command of each, so that relationships between the members of the two groups are as much as possible on an advisory basis. This has much to recommend it and may be the best solution in many instances. The writer has some preference for greater intermingling. This should enable us to make maximum use of the talents available and help to prevent the growth of entrenched interest. This solution is contingent on our ability to solve the concurrent problems, however.

Some may feel that the writer's emphasis on the development of the civilian staff is at the expense of the officer staff. Optimistically, he hopes that the opposite is true. For example, many may feel that the assignment of officers to work for civilians may demean the status of the officer and thus make his career system less attractive. And yet what better training is there for a person who on other assignments is himself supervising mixed groups of officers and civilians? He will certainly be placed more in competition with civilians. Yet is this not to the benefit of both groups?

One extremely important facet of this problem which is worthy of a book by itself is the system of officer rotation. There is space here only to question whether the costs have been added up as carefully as the advantages, and whether all possible modifications of the system which might minimize the costs have been considered.

This is only one of many loose ends.

If the above observations and suggestions have any merit, it is hoped that they point out an area which deserves more attention, which challenges our ingenuity, and which promises substantial rewards.

SHIP VIBRATION PROBLEMS

N. H. JASPER

THE AUTHOR

The author received his Bachelor's degree in Mechanical Engineering from the College of the City of New York in 1941. He joined the Scientific section of the Puget Sound Naval Shipyard in 1941 and worked there until transferred to the David Taylor Model Basin in 1946 where he has primarily been concerned with applying vibration theory and experimental methods to the study of ship structures. He studied, since 1941 at the University of Washington, the George Washington University, the Graduate School of the Bureau of Standards and the University of Maryland from which he received the Master of Science degree in 1950.

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One may ask the question: What is a vibration problem? In general any phenomenon in which some quantity varies with time may fall into this category. Mostly however, we think of a vibration problem as one which involves undesirable oscillatory motions and their consequences. Usually it is these consequences which make the vibration a problem.

I will discuss here, primarily, those problems about which something can be done *now* for the ship designer and the shipbuilder, hoping, in this manner, to call attention to the facilities available at the Taylor Model Basin to help build better ships. There is of course considerable research underway also, but the fruits thereof lie in the future and will not be a subject of this paper.

Consider first the ship in its entirety. We all know that ships do vibrate and that, to most people, vibration, if recognized as such, is undesirable. An ocean liner can get a bad reputation and lose business because of it. Aside from physiological effects, hull oscillations may induce excessive vibration in component parts of the ship such as gun directors, masts and decks, resulting in maloperation of equipment or, in some cases, structural failure. Fatigue failures, for example, are vibration failures. The hull vibration is caused by oscillatory forces which act on the ship. The origin of the forces may be the rotating pressure field due to the propeller, unbalanced forces generated by machinery and shafting or the action of the sea.

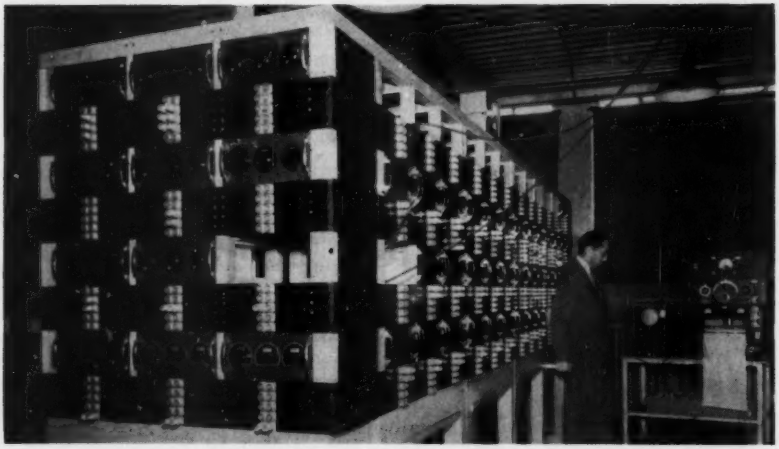


FIG. 1.—TMB A.C. Network Analyzer.

A ship, like other structures, has certain natural frequencies. Whenever the frequency of an exciting force coincides with a natural frequency, we have what is called a resonance and such resonances may result in very large vibratory motions and structural failure, even if the exciting force is quite small. It is therefore highly desirable to avoid resonances.

A ship's hull usually has one or more natural frequencies of flexural vibration which might coincide with the shaft RPM. It is desirable therefore to determine these natural frequencies before choosing the shaft RPM, especially for commercial vessels which are often designed to operate at a fixed speed.

We are in a position to determine the natural frequencies of flexural hull vibration if we are given the distribution of weight, sectional moment of inertia and the area of the plating which is resisting shear for a particular ship. A set of body lines is helpful in determining the effect of the virtual mass of water on the vibration characteristics. In addition to the natural frequencies the modes (physical form) of these vibrations can also be determined. To do this work by purely analytic means would be a practical impossibility. At David Taylor Model Basin there is a network analyzer which consists essentially of convenient means for setting up combinations of passive circuit elements, See Figure 1. Once an electrical analog of a vibrating non-uniform beam, such as a ship, has been established it is an easy matter to convert the mechanical units such as mass or bending stiffness into equivalent electrical circuit parameters. In this manner an electrical circuit is obtained which behaves analogously to the ship. By determining the resonances, currents and voltages of this circuit, they can, by the use of suitable conversion factors, be converted to the desired mechanical values, i.e., to natural frequency of hull vibration, shear forces, bending moments and vibratory motion. The accuracy of the computed natural frequency is dependent primarily on the accuracy of the physical data. Frequency determination, accurate to within 10 per cent. can be made. The analog itself is accurate to about 2 per cent; it is in the evaluation of the stiffness and inertia

parameters that the greatest errors occur. The time required for such a determination is about 3 days for 2 men provided the distribution curves of section properties are furnished. Given the natural frequencies of hull vibration, the designer can select the shaft speed so as to stay clear of hull resonances and he can check the designs of masts, gun directors, etc., to avoid resonance with the lower modes of hull vibration.

Next consider the longitudinal vibration of the ship's propeller-shaft-machinery system. As the propeller turns, an axial oscillatory force acts on the shaft with a frequency of application n times the shaft RPM where n is the number of blades per propeller. If the frequency of force application coincides with a natural frequency of the system which is composed of the propeller, the shaft, thrust bearings, machinery and the elastic connections to the hull, large motions may occur. This will result in excessive wear or breakdown of couplings, bearings, and of the piping connected to the system together with consequent objectionable noise. Such a vibration is especially dangerous, as experience shows, when the resonance occurs with high thrust variations. The magnitude of the vibration at resonance will of course be determined by the damping and exciting forces; however every effort should be made to avoid resonances. In order to study a given design it is again convenient to utilize an electrical analog of the mechanical system. In this way it is an easy matter to determine, for example, the variation in natural frequency, with location of the thrust bearing, for the case of a thrust bearing built independent of the gear case. In a similar manner one can determine the effects of variation in foundation stiffness, shaft size, damping forces, etc. It should be noted here that this type of problem can also be treated analytically without the use of the analog or computing machines. However, the use of these devices is a great timesaver. The time required for solving a particular problem of this type on the analog, given the physical constants of the system, is about 2 man-days. The accuracy of the frequency determination is about 5 per cent. The torsional natural frequencies of machinery systems are also readily determined by use of the analog. The time savings made possible by the analog can be visualized if one considers that simply twisting a few knobs produces an electrical model of a new design.

Another problem, somewhat more complex than the preceding one, is the determination of the critical frequencies of lateral vibration of the ship's propeller shaft system. These motions are often spoken of as whipping or whirling motions. See Figure 2. Here one needs to consider the flexibility of the bearings and bearing supports as well as the flexibility of the shaft itself. The mass and inertia of the propeller, the effect of entrained water and the gyroscopic effect of the rotating propeller all need to be considered in the frequency determination. An electrical analog of this system is shown in Figure 3 which, with certain omissions, also represents a vibrating hull girder. The most important natural frequency here is the shaft RPM or first order whirl which is always excited to some extent by unbalance in the propeller or in the shaft. Of lesser significance is the blade frequency whirl (RPM $\times$ number of blades) which may be excited by hydrodynamic forces. A considerable variation in the natural frequencies can be obtained by utilization of different types of bearing materials. It may be of interest that the gyroscopic effect of the spinning propeller is to raise the natural frequencies for forward whirl (whirl and spin are in the same direction) whereas the frequency is lowered for counterwhirl. The existence of higher order whirls is less well known than that of the first order (RPM fre-

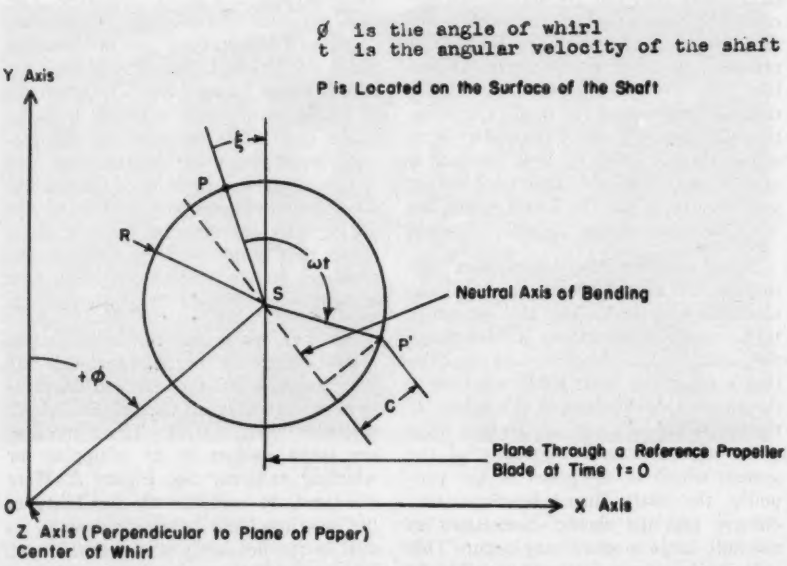


FIG. 2.—Section Through the Whirling Shaft. The whirling motions considered here are restricted to the type in which the axis of the shaft lies in a plane which contains the radius OS and the Z-axis (curvature in one plane only).

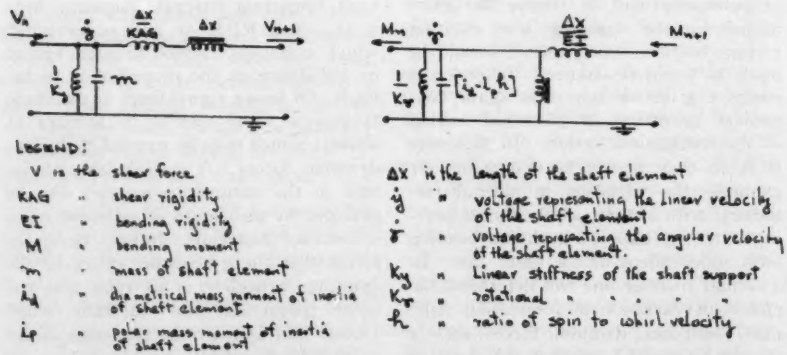

Vn
Δx
KAG
Δx
Vn+1
m
Mn
Δx
EI
Mn+1
[iφ-Ipfh]
LEGEND:
V is the shear force
KAG " shear rigidity
EI " bending rigidity
M " bending moment
m " mass of shaft element
iφ " the inertial mass moment of inertia of shaft element
Ip " polar mass moment of inertia of shaft element
Δx is the length of the shaft element
ẏ " voltage representing the linear velocity of the shaft element
θ̇ " voltage representing the angular velocity of the shaft element.
Ky " linear stiffness of the shaft support
Kφ " rotational " " " "
fh " ratio of spin to whirl velocity

FIG. 3.—Electrical Circuit Representing an Element of the Whirling Shaft Including the Effects of Rotary Inertia, Gyroscopic Terms and Bearing Flexibility.

quency) whirl. Given adequate data on the physical parameters of the system the fundamental whirling frequency can be determined within an accuracy of about 10 per cent. Computations have been carried out both analytically and in some cases by use of the analog for a wide range of shaft-propeller designs for tankers, Liberty ships, destroyers, aircraft carriers and PT boats. In all cases where experimental data were available the check was good.

The items presented so far concern fairly well defined problems to which fairly definite answers can be given. There is room for improvement in present methods but nevertheless progress has advanced to the point where a reasonable degree of confidence in the results is permissible. There are other types of vibration, or for that matter strength problems, which cannot be treated satisfactorily by the methods outlined before. Some of these will now be discussed.

Secondary structures such as masts or gun directors are often too complex to permit sufficient simplification to allow a valid analytical treatment. In such instances it may be best to study the behavior of the structure on a model scale. For example, the natural frequencies of vibration of a new type of aluminum tripod mast have been found from an ⅛ scale model. The maximum deviation from the full scale values was 8 per cent. However the value of a structural model is very much dependent on judgment in the model design as well as care in fabrication. Therefore one should consider such studies only if better means are unavailable.

A model of a propeller shaft system which permits variation of bearing spacing, bearing flexibility and propeller characteristics has been built. See Figures 4 and 5. By means of this model a wide range of ship installations may be modeled.

FIG. 4.—Model for the Study of Propeller Shaft Whirl.

FIG. 5.—Shaft Failure Due to Whirling Resonance.

A quite different type of problem often occurs on existing ships or structures. They may be thought of as trouble shooting. For example: the skipper of a particular ship may complain that his ship is shaking all over, kindly fix it. It may be a serious matter or it may be an exaggeration, in any case it is an immediate problem to be taken care of at once. The usual procedure is to send engineers with measuring equipment to the ship in order to get quantitative data, such as the amplitude and frequency of the vibratory motion or stresses at selected locations and ship speeds. Often the data thus obtained give an immediate answer to the cause, for example a bent propeller, or a local resonant structure. Sometimes the problem may initiate a design study resulting in eventual redesign of certain equipment or structures. With the trend toward higher power and speeds in ships design, vibration problems appear which were not apparent in prior years.

One basic question, often posed, is: What is the permissible level of vibration? The answer to this question cannot be given very specifically at present. The vibration is too great when it becomes objectionable. The definition of "objectionable" is of course the crux of the situation. What may be entirely acceptable for a passenger liner will be horrid for a submarine. What may be acceptable from a standpoint of structural strength may be entirely too severe from physiological consideration. What was acceptable five years ago may not get by tomorrow; that is the tolerance to vibration may change with time. It is one of our objectives to establish reasonable acceptable levels of vibration for different classes of ships and for different locations aboard ship.

Another type of vibration, although not generally thought of as such, is the rigid-body oscillatory motion of ships, namely: rolling, pitching, heaving and yawing. Information as to the amplitude and frequencies of these motions of considerable practical interest to designers of ship structures and of marine equipment. The motions of most importance are the rolling and pitching motions. The structural designer must evaluate the dynamic forces associated with such motions and the equipment manufacturer must know the environmental conditions under which his equipment is to operate. Very little actual field data are available on these motions. Automatic equipment has been and still is under development at the David Taylor Model Basin which will provide such data for different types of ships under actual operating conditions. It is hoped to present such data in such a way that the probability of exceeding any specified pitching or rolling motion will be given in graphical form for given ship types.

This article presents an outline of the work that the David Taylor Model Basin is doing in the field of vibration with emphasis on items that are of direct interest to those concerned with structural, machinery and equipment design. It is hoped that the paper has been able to present some of the facilities available today for building better ships tomorrow.

THE ART OF THE PRACTICAL ENGINEER

ACKNOWLEDGMENT

This article is an abridged version of the presidential address of SIR DAVID PYE to the Institution of Mechanical Engineers on October 17, 1952. It was published in the October 24, 1952 issue of "Engineering."

The national problem of providing the engineers that the country must have is vital and unsolved today, and when the question of my presidential address was first discussed it was sugeted that an appropriate subject would be engineering education. I am happy to think that there are probably some members of my audience who have not read as many reports and letters to *The Times* on that subject as I have done. I shuddered at the thought of adding yet another address to the mounting pile of reports, memoranda, lectures, and White Papers, with which any member of our Education Committee is already faced. I am afraid those concerned with technological education are a little tired of reports and addresses; we all know what we want to achieve, and if we do not know how to get it that is not for lack of papers and printer's ink.

I decided therefore that if I were to talk about engineering education it must be from a text of broad and simple significance drawn from my own experience, and that I must leave to the experts, at another time and place, important questions like the proper balance between the teaching of the fundamental and applied sciences. Looking back on my experience, I ask myself whether I have a worthwhile contribution to make. I think it is possible that I may have, because of my earlier experience in teaching young men how to pass examinations in engineering subjects, followed up later by the years during which I occupied a ringside seat, as it were, watching the real work of designing and producing in the shops the new things that were to change the course of engineering. These two periods have left me with a profound sense of the yawning gap between the product of a university course and the qualified engineer, and—more particularly—of the importance in any organization of the man of whom one feels that he is by nature an instinctive engineer, though it may be with little or no scientific training as ordinarily understood.

Of course, none of us ever imagined a student and an engineer to be the same thing. Before he can be an associate member of this Institution, the university graduate must have supplemented his theory by practical training and responsible experience; and this combination may provide the basis for his becoming a real engineer. But I have been lead to feel how small a part of the way all the theoretical training, in which we teach him to manipulate

formula on paper and to record experiments in a laboratory, can ever take him; by the time he has "grown up" as an engineer, indeed, his book learning will have become hardly more than a vaguely-felt background to his experience. For the art of engineering includes a very great deal that lies outside of formulated theory. The rule of thumb plays, and will always play, an important part; and rules of thumb are accumulated by experience.

I have said that all engineers know what they want to see achieved by engineering education; I take that to be a young generation coming forward eager to take responsibility and competent to do so at all levels, each in his proper sphere. I emphasize "at all levels" because, although the majority of those who are vocal on the subject of engineering education tend to come from the universities and are apt to concentrate upon training at the higher levels, I suggest that the technical and technological man-power of the nation should be thought of as a whole, beginning with the skilled craftsmen and including draftsmen, designers, research and development staff—junior and senior, and those who become managers and directors. Men of special quality are to be found at all levels, and it should be the constant aim of those in authority to spot them early and to bring them forward to the maximum of their capacity.

I want to take as an example designers; not because I have ever been a designer myself, but because I doubt whether more than a very few of the able men who are teaching at universities and technical colleges normally reflect much on the work of a design section, which is the creative center of any works, and because what I shall call the creative designer may begin to show his quality when he is a junior draftsman, and the creative spark is precious and must be fostered above all things. Recently, I was at a small works where you might say that the spirit of design was rampant; where they produced the most complex machines and seldom built more than two or three of the same type. I asked the managing director: "How do you recruit your designers for this sort of design work?" His reply was that for the most part they were recruited direct from school. Continuity of employment, of course, was an essential factor; within a year or two a few of the recruits began to show the necessary spark of originality for promotion to group leaders, and ultimately to designers and above.

It is obvious that these men, who come up the hard way, must have constantly before them the essentially positive aim of the engineer: to devise and construct something that is better for its purpose, whatever that may be, than that which has existed before. While they are gaining their background at evening classes, these budding designers have all the time the stimulus of meeting known requirements. Now it is just this positive aim of the engineer in his profession about which, as it seems to me, there is a fundamental difficulty in the presentation of any real picture as a part of a university course. A university, it is true, is a place of learning and research, but it presents itself so often in the mind of the student as a place where he has to acquire a degree in the shortest possible time. That does not make the atmosphere conducive to the blossoming of a flair for ingenious design; nor are university examinations the circumstances in which it would be detected. They do not lend themselves readily to the assessment of a man's quality as a designer, and there appears to be a danger that where there is no clear method of differentiating between the good and the poor student, the teacher and examiner may lose interest in design as a subject in the award of a degree—quite apart from the fact that

the teachers and examiners are for the most part themselves of an analytical turn of mind; skilled in those methods of research whereby such mighty results have been achieved, but only incidentally interested in new opportunities for design and construction.

The atmosphere of a laboratory is fundamentally different from that of a design office, which should be more like an artist's studio or an architect's *atelier*. In a design office, things are not right or wrong; trial and error lead gradually towards the best compromise in the special circumstances. And since compromise is fundamental in the solution of almost every engineering problem, as it occurs in practice, the student at some stage should be made familiar with it. There is a real danger in concentration upon the "examples class," admirable as it is for testing the understanding by a student of what he has been taught, and for the exposure of muddled thinking, but deadening to originality of thought. In working out examples the student employs well taught mathematical techniques to find the solution of problems that are analogous to those in engineering, but different in form from those encountered in practice.

The growing tendency today is to recruit from among those who have taken university degrees; we may perhaps assume as a working hypothesis, but with many notable exceptions, that as a class the ablest recruits to the engineering profession find their way to the universities. We should therefore look to the universities to feed back into industry first-class minds with a well-balanced scientific and technical background; many of them minds that are ready to be stimulated to creative activity by contact with the practical needs of industry. Are we choosing the right way to set about the task of providing the needed background while at the same time retaining sufficient flexibility in the courses to allow the spark of originality, when it exists, to grow? I have touched already upon some of the fundamental difficulties of what I have called a more positive approach to engineering education as contained in a degree course; but even if one cannot hope to introduce the atmosphere of a design office it would be something achieved if the university student could be made more aware of the importance of design in the progress of engineering. I know of a few courses of university standing where a serious effort is being made, chiefly at the post-graduate stage, to introduce some of the realities of the design office to a small team of students; but it is always subject to the handicap that the atmosphere of discussion and compromise can become real only if it is confined to a small group. Ideally the group should be organized by a man who is actually engaged in responsible design work himself; he is therefore not primarily a teacher and serious difficulties of administration are introduced.

Nevertheless, the problem should be faced. Can it be said that the creative mind is typical of the university graduate in engineering today? If it is not, can this deficiency be laid to the charge of the courses provided, and are there any practicable modifications by which the position can be improved? To my mind, questions should first be asked about the methods whereby selection is made of those young men who are to be allowed to embark upon honors degree courses. I would suggest that this selection is in danger of being left too much in the hands of the mathematicians. Some chemistry and physics may form part of the qualifying examination; but it is a candidate's ability in tackling the mathematics that is often crucial. Mathematical tests are ideal from the examiner's point of view; easy to set and easy to mark; producing a definite order of merit, easily translated into first-, second-, and third-class honors. But indicative of what? Not, certainly, of the

seeds of a creative or instinctive engineer.

The mathematical test contains no element whatever of the positive approach to engineering education that would from first to last place some emphasis upon the ultimate aim of the engineer; which is to devise and construct. Do not imagine I am belittling the importance of mathematics as the basis of an engineering education, or, at its higher levels, as equipment that may be essential for some research engineers. All I am suggesting at present is that to rely upon competence in mathematics for the selection of young men to be admitted to an honors course in engineering is to risk the exclusion of quite a number who might have developed into the finest engineers. There are those who do not take kindly to the mathematical approach, and they should not be thrown out at the first hurdle. Under present-day arrangements, and with the mathematical standards now expected, it is largely true to say that the mathematicians decide who shall be our future university-trained engineers. And this is the more dangerous if it is true, as several men have assured me they believe, that a moderately clever and hard-working boy in the hands of an able teacher can be coached in mathematics to show a form in an examination that is quite unreal as an indication of his general intelligence.

An understanding of the processes of mathematics up to, say, the solution of first-degree differential equations is desirable as forming part of the normal shorthand used in engineering education. At a much higher level, mathematics can be a powerful tool in the hands of anyone competent to use it. But, in my opinion, it would be wise to keep the two categories of mathematics quite separate, and to encourage only those young engineers to whom it comes easily, as a friendly tool, to attempt to go beyond the stage of understanding it as a form of shorthand. For it is only they who will be the better engineers for the study of it. If the mathematicians are allowed to get the bit in their teeth and go galloping off with half of their unfortunate students trailing behind, unable to keep up, then the only benefit those students will ever get from their higher mathematics will be a few odd marks at their final examination, at the price of many wasted and painful hours that might have been much better spent.

Having made our selection of those who are to be given the elements of a basic training in engineering subjects—in machine design, prime-movers of various kinds, hydraulics, and applied electricity—we proceed in most engineering courses to put the young men into a mental "strait jacket" in which for a year they study mathematics, physics, chemistry, and machine drawing, with scarcely a hint of real engineering to encourage them. In the second year they are taught to apply scientific techniques to the solving of simple engineering problems, and at the same time to enlarge the scope of their analytical work—which is to come in the third year—by reading and descriptive exercises. The third-year work is devoted almost entirely to the solution of problems analogous to those which arise in engineering practice; and the solutions of nearly all these problems involve mathematical techniques. The students who reach their final year, therefore, do so by passing tests and examinations in technical and scientific subjects only, and there is no place in many university engineering departments today for a man who has not acquired the technique of mathematical analysis in the solution of technical problems. He may never have been brought into touch with design as the living stimulus towards improvement of function. All the pressure of an over-full program is brought to bear upon the somewhat sterile pursuit

of solving artificial problems in engineering, invented for examination purposes.

I speak as one who has had no direct contact with engineering teaching for many years, and perhaps I should hold my peace. But I have had many discussions with engineering teachers, and have compared modern examination papers with those of my own student days. Current papers reproduce the character of their predecessors of 45 years ago with extraordinary fidelity, except in details and except for the higher standard of mathematics often expected. Moreover, professors whom I have consulted have told me that, whereas when they were themselves students time was spent in going through the steps of actual designs, of late years pressure on the time-table from all sides has forced them to cut out even those attempts at a positive approach. To work through the steps of a design will not carry a class very far towards the realities of a design office; but must even these attempts to retain some constructive element in the training of our best students be abandoned? Cannot time be found if we are sufficiently drastic with the present time-table? You could turn out a very good engineer by teaching a man nothing but physics, with some chemistry and mathematics (not too much unless he is a natural mathematician) and engineering drawing; and by leaving all the rest that he finds he needs in practice to be picked up by post-graduate reading.

My impression, for what it is worth, is that many university courses have become overcrowded and stereotyped and lack the flexibility to allow for the exceptional man. I know of a few teaching departments of university rank—but I believe them to be a small minority—where a serious attempt is being made to give some experience of the reality of design procedure. In too many engineering courses, however, we seem to be making little attempt to develop more than one side of an engineering student's work—the analytical and mathematical one—and not to be giving the potential works manager, or the administrator, any greater opportunity to show his quality than that given to the designer. In this connection the interesting innovation at Durham University described by Professor Burstall to the British Association a year or two ago is of particular interest.

My final remark in this connection—deliberately provocative—is that I deplore the almost pathetic faith shown in the advertisements from all Government departments (and some research associations, who should know better) in the first-class or second-class honors degree. May I suggest that there are jewels to be found, by those who will take the trouble to look, among the supposed refuse of third classes and passes. An ounce of intinct is worth a pound of information.

I have called my address "The Art of the Practical Engineer" and I have spoken of the "art of engineering" because I want to insist that so much of the work of the designer, in mechanical engineering especially, calls in practice rather for the instinctive skill of the artist than for the calculations of the mathematician. As an example of what I mean, Fig. 1 illustrates the fully-shrouded impellers of the centrifugal superchargers in the Proteus jet engine and the Hercules piston engine. In front of each is the forging—the one in steel, the other in aluminum alloy—from which each impeller is produced from the solid by a continuous milling operation. The relative movements of the work and of the cutter are controlled automatically so as to provide an almost continuous machining process throughout. Fig. 2 shows a milling machine in operation on one of the front pockets of the steel impeller.

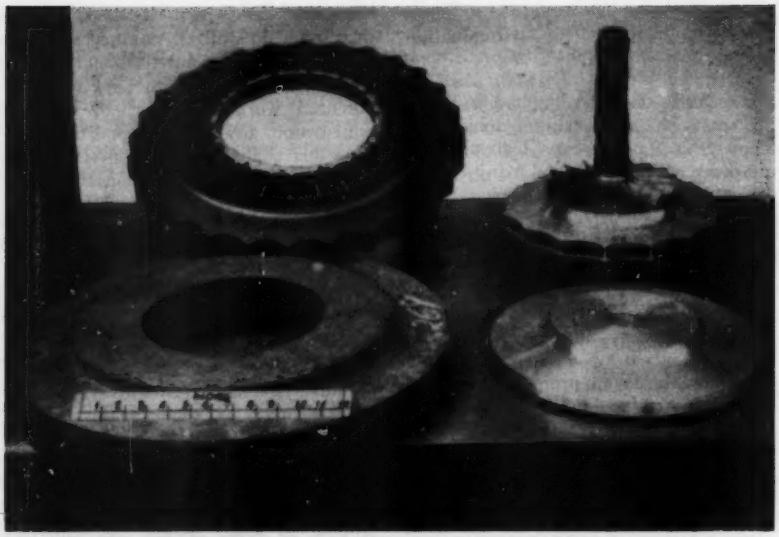


Fig. 1—Shrouded impellers, and forgings from which they are made.

I should perhaps explain, for the benefit of those not familiar with centrifugal superchargers, that air enters the impeller in an axial direction—parallel to the shaft—and leaves it in a direction at right-angles with the shaft, through the slots round the periphery of the wheel. The steel and aluminum-alloy impellers revolve at speeds of about 12,000 rpm and 20,000 rpm, respectively, and the efficiency of the superchargers depends upon the exactly correct shaping of the passages, which in these designs have to be milled out of the solid forging. I think you will agree that the mind capable of conceiving and designing the milling machine to carry out the extremely complex movements involved exhibits an imaginative power of a high order. Mathematics, apart from simple arithmetic, has no part to play. There is an engineering intuition required in such a design, something born of experience, which arrives at conclusions by no traceable process of analysis as to what can or cannot be made to work. Such an instinct goes a long way towards the make-up of the "creative engineer," or the man with a touch of the artist in his composition. Here I have used the words "artist" and "creator" as almost synonymous terms, and indeed I think that every artist must be in some sense, a creator.

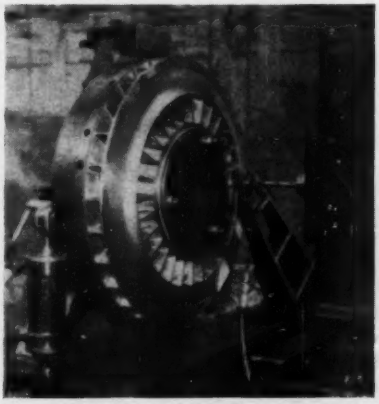


Fig. 2—Milling front pocket of impeller.

Normally, when we speak of art or of an artist we think of the fine arts—drawing, painting, or sculpture—and it is perhaps worth pointing out that the creative engineer and the artist have this in common: that, just as the engineer without detailed knowledge of his materials is like a blind man groping in the dark, so the painter or sculptor is helpless, dumb, until he has a knowledge of his materials and what can be done with them—whether paints or marble—which is so intimate that he can make them express not only his concrete needs but his ideas also. The engineer is not as a rule called upon to express only ideas in his creations; although certainly the engineer who designed and built the Skylon at the South Bank Exhibition last year may be said to have done so, and he—quite as much as the painter and the sculptor—would have been helpless without a very accurate knowledge of his materials. If you are going to create something, whether it is a work in one of the fine arts or a locomotive, an essential prerequisite is complete familiarity with the materials to be used in creating it. That is universally true.

The supreme phenomenon of the creative engineer is found when a designer of genius appears, almost untaught. The classic example must surely have been Sir Henry Royce. As a young man he became a tester in one of the new electric lighting companies of that time—strange training indeed for the inspired designer of airplane engines whose genius enabled this country to hold the speed records of the world, by land, sea, and air, all at the same time. Of course, his inspired faculty for designing complicated mechanisms was based on sound science; but he was largely self-taught. In all he did his work showed unusual exactness and thoroughness, and he had a phenomenal memory. He once remarked, in reply to an inquiry: "My night school education made it imperative never to forget anything that was worth remembering, and I have never outgrown the habit." He was always intelligently absorbing and selectively remembering, so that in time he acquired that distilled wisdom which is garnered from wide experience and held ready to be applied to each new problem as it arises.

Royce was a man who reached his mature skill as a designer almost without formal training. Our great benefactor James Clayton, in the field of textile machinery, was another. Such men are rare, and with the growing complexity of engineering are likely to become rarer still, for it is only men of genius who can now survive the handicap of an absence of early training. But if we go outside the class to which the word "genius" can apply there are many men, both trained and untrained, who have a certain audacity of imagination, or peculiar perceptiveness, which puts them into a special class. And such men may appear, as we have seen, at all levels. They may or may not show originality as designers. There are other ways of being classed as a creative engineer. I have in mind, for example, a man who was in charge of the test-beds at a well-known works; an uneducated man, but one with an uncanny instinct for machines. If anything were going wrong, and puzzling those responsible, it would always be worthwhile to give this man his head. He would often "scent out" the trouble after trying this and that; sometimes for what appeared to the experts to be faulty reasons. It is this kind of instinct which, in taking a broad view of engineering training, we should strive to preserve and develop no less than that of the successful designer. I have in mind, too, another type of man whose skill may be of peculiar value within a limited sphere, a typical product of the works floor; the man of supreme skill of hand in some specialized line; the manipulative wizard, one might call him, whose work has no more of the creative

faculty than that of a juggler, except possibly for creating records of speed in manipulation. And his skill is valuable only if it cannot be copied and multiplied by machines. Sometimes it cannot, and the man gets his proportionate reward.

Apart from such men with special qualities of instinct or skill, I come back to the man who has the truly creative faculty of the designer. When discussing design one should speak not of an individual, but of a team; though a team with an acknowledged leader. Probably there is no department in a works where leadership is so important, or where the stimulus of one man may be so widely felt, as in the design office. And in speaking of the creative designer one must not forget to mention, in passing, his natural complement: the wise man of varied and long experience, the critic rather than the originator. One might perhaps suggest that every successful team must have its *advocatus diaboli;* its critic as well as its creator; the successful practitioner to balance the brilliant originator, the latter always fertile and the former patiently backing him up and getting the best out of any novel design. Sometimes, of course, the qualities of the innovator and the successful practitioner are combined. One suspects that they were so combined, for example, in Sir Charles Parsons. Genius as a designer in many fields he certainly had; and also the wisdom of the successful practitioner; but who knows there was not also a valued critic in the background?

All these men practice the art of the engineer: to devise and create. Their importance cannot be overestimated. And along with our designers of genius and our successful practitioners we must cherish also those types one may meet in any works from time to time: men who would never have passed the first of the examinations considered essential among the qualifications of an engineer, who may give the wrong reasons but will find the right answers. They, within their range, are, like the great ones, guided by an instinct that seems to achieve a distillation of relevant experience and can be counted upon to solve a practical problem in the most direct way.

IS STANDARDIZATION A SCIENCE?

ELLSWORTH F. SEAMAN

THE AUTHOR

Studied Electrical Engineering at the Carnegie Institute of Technology, Pittsburgh, Pennsylvania. After leaving school in 1923 his professional career between 1923 and 1931 consisted of engineering work with electrical utility companies in Pennsylvania, New York, Alabama, and Texas. In 1931 he entered the employ of the Bureau of Engineering. During his nineteen years' service with the Navy Department he has been in electrical engineering work in the research, development and standardization categories. He is currently the Bureau of Ships' head of the Standardization and Conservation Planning Branch. In this capacity he serves as the central departmental administrative point for the Armed Services Electro Standards Agency, Fort Monmouth, N. J., and acts as custodian of a NATO project and chairman of several committees of the International Electrotechnical Commission. Mr. SEAMAN is the recipient of both the Navy Meritorious and Distinguished Service awards. He was named as the "Standards Personality" of the month in the February issue of "Standardization."

ABSTRACT

Standardization effort is in many instances seriously retarded through lack of an awareness of certain fundamental principles that have never been clearly set forth. This is true even though standardization finds its greatest application in the engineering field where an analytical approach develops the facts and where the use of basic scientific concepts lead to the ultimate solution. It is the purpose of this paper to show that the engineering approach applies to standardization as such. This is done by analyzing the different aspects of standardization, grouping them under generic categories, and then defining them in terms of theorems.

INTRODUCTION

To answer the question of whether or not standardization is a science one must be provided with a definition in practical, rather than absolute terms, wherein a clearcut distinction is made between an art and a science. Thus for the purpose of this discussion a science is considered as a field of endeavor wherein comparable results may be obtained by any worker who adheres strictly to the

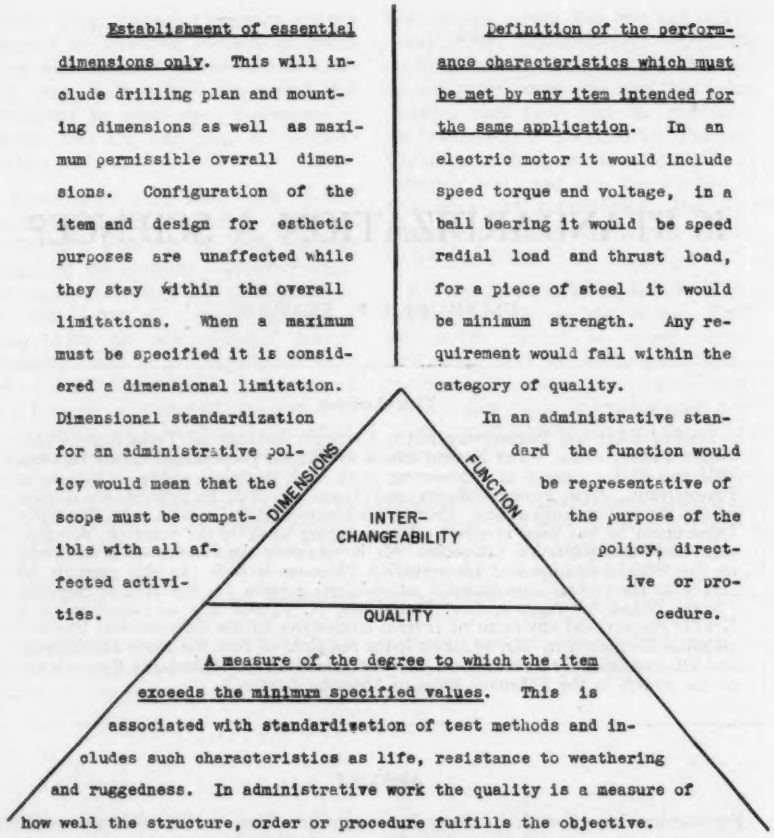

Establishment of essential dimensions only. This will include drilling plan and mounting dimensions as well as maximum permissible overall dimensions. Configuration of the item and design for esthetic purposes are unaffected while they stay within the overall limitations. When a maximum must be specified it is considered a dimensional limitation. Dimensional standardization for an administrative policy would mean that the scope must be compatible with all affected activities.
Definition of the performance characteristics which must be met by any item intended for the same application. In an electric motor it would include speed torque and voltage, in a ball bearing it would be speed radial load and thrust load, for a piece of steel it would be minimum strength. Any requirement would fall within the category of quality.
In an administrative standard the function would be representative of the purpose of the policy, directive or procedure.
DIMENSIONS
FUNCTION
INTER-CHANGEABILITY
QUALITY
A measure of the degree to which the item exceeds the minimum specified values. This is associated with standardization of test methods and includes such characteristics as life, resistance to weathering and ruggedness. In administrative work the quality is a measure of how well the structure, order or procedure fulfills the objective.

FIG. 1—Triangular Interchangeability Concept.

* A variation of this appears in the February 1952 issue of Standardization. This is reproduced through courtesy of the American Standards Association.

governing precepts or theorems. As opposed to this, an art, to be successfully practiced, depends on intuitive skills or talents which are inherent characteristics of specially adapted individuals. It is therefore not possible, except with indifferent success, to set forth scientific rules which will guarantee reproducible artistic results.

An essential part of an analysis of standardization is a definition of the term itself. The word is generally considered so obvious in meaning that it requires no definition and for this reason it it loosely applied. *Standardization, in the generic sense, is the sum total of effort that either directly or indirectly results in the ultimate establishment of some form of standard.* This end result may be either a new standard or it may mean the modification of an existing standard. A standard as used here is all-

inclusive in that it covers specifications, codes, practices, procedures, policies and many other variations, all of which can be reduced to the common denominator of repeated usage.

The past experiences of many who have dealt with groups seeking common agreement would indicate that the chances of achieving success are never immediate and usually doubtful. These conclusions, while generally correct, do not reflect the science-like aspects of standardization but indicate instead the lack of scientific approach. The question then is: What are the scientific principles that can be readily applied by standards projects participants in arriving at early mutual agreement as to a workable plan? The answer to this resides in the careful analysis and classification of all valid and non-valid approaches to the solution of standardization problems. These analyses have been made and the results are set forth below.

I. THE TRIANGULAR INTERCHANGEABILITY CONCEPT IS COMMON TO ALL STANDARDIZATION, AND DEFINES REFERENCE AREAS OF AGREEMENT IN TERMS OF DIMENSIONS, FUNCTION, AND QUALITY.

Figure 1, while brief as to explanation, does contain sufficient detail to serve its purpose, namely: to set forth the basic categories representative of standardization objectives. Analysis of controversial points and comparison with boundary lines dividing the essential from the non-essential, can, in many instances, eliminate deadlocking differences which are found through analysis to be unimportant.

II. STANDARDIZATION IS COMPOSED OF THREE CATEGORIES OF EFFORT NAMELY: ADMINISTRATIVE, TECHNICAL AND TERMINOLOGICAL.

The sum total of information contained in Figure 2 is intended as an indication of a standardization program which is general in scope and relatively comprehensive. The reason for its use in this instance, is to orient the thinking as to scope and to point out the proper channel for solution of difficult problems. This latter aspect is closely associated with Theorem III which follows. Figure 2 should not be interpreted as an organizational chart governing the duties of personnel. It classifies work as to type. The points at which each type of work is performed will vary depending on the individual organization concerned.

Decision on administrative matters is normally allocated to the non-technical level so that time used by engineers or specification writers in working out a change in format would be wasted except when justified by unusual circumstances. The same is true of matters involving policy such as certain inspection problems, and whether a performance* or design type of specification shall be written. The importance in the separation of administrative and technical problems cannot be overstressed. Almost all of the delays in reaching standardization agreements can be attributed to administrative problems. Valuable time is lost when the problem is not referred to the appropriate level for decision along with constructive recommendations.

The technical phase of standardization

* Performance specifications define the minimum performance requirements of the product whereas design or formulation specifications set forth detail design requirements or specify the exact ingredients of the product.

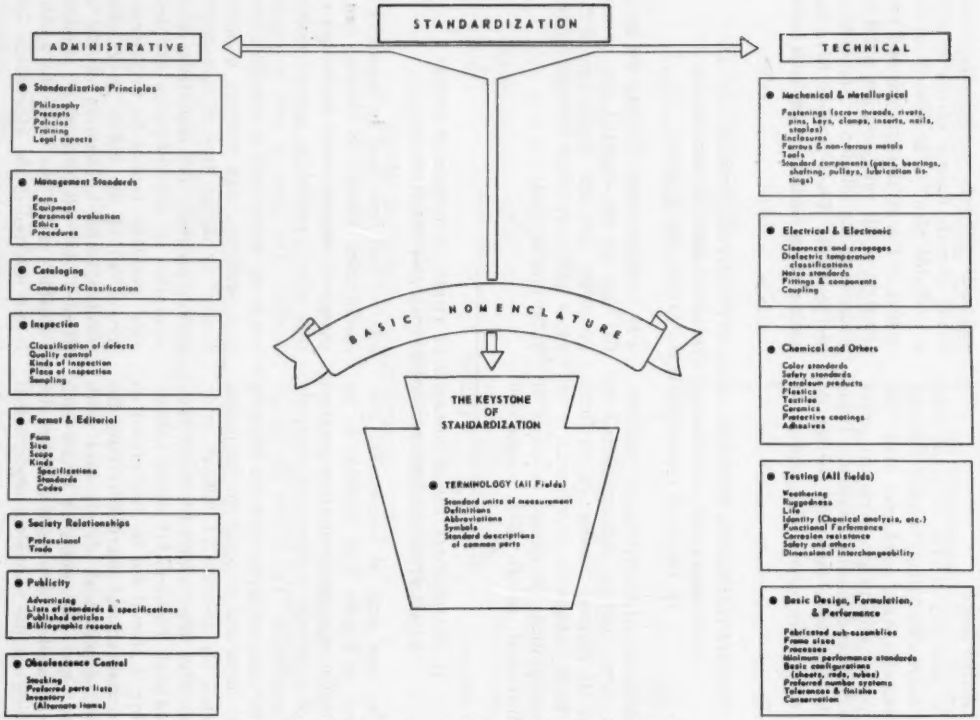


FIG. 2—Component Efforts of Standardization.

is confined, as discussed in Theorem I, to the solution of technical problems concerning interchangeability. The work in order of ascending technical difficulty may be listed as: (1) dimensions, (2) function, and (3) quality. This latter phase of the work may become highly technical and difficult in character where the development of accelerated life tests is not the least of the problems involved. The technical part of standardization work consists of using to best advantage the engineering and other sciences forming a part thereof.

III. DIFFERENCES MAY BE RESOLVED THROUGH THE PROCESS OF FACT-FINDING WHICH, IN OPERATION, IS THE SUMMATION OF FACTS BETWEEN PERTINENT LIMITS AND THE EVALUATION OF SIGNIFICANCE OF EACH FACT WHEN CLASSIFIED ACCURATELY UNDER THE GENERIC FAMILY GROUP TO WHICH IT BELONGS.

It is the rule rather than the exception that standardization agreements are reached only after a laborious and circuitous line of reasoning where the real issue is obscured either by generalities or by a logic based on false premises. This condition can be eliminated by the recognition that the services of an unbiased fact-finding group should be made available for every standardization project, if and when needed.

It would be the function of such a group to analyze all cases referred to it by reason of a stalemate or undue delay occurring at the project working level. Through this procedure it would be possible to separate the administrative from the technical problems and to refer each to the proper level for decision and action. In instances where guiding policy decisions should be made by management such questions would be referred to the top level and the decision would govern the immediate action in addition to serving as a precedent for future similar cases.

Figure 3 is descriptive of the manner in which the fact-finding procedure operates. It is the theme of this chart that the preferred handling of any standardization project is through its regular routine channels without recourse to special measures. Should this procedure fail the second best course of action is to properly separate and analyze the difficulty, at project level, and then refer the analysis to the appropriate echelon for decision. If the problem cannot be solved in this manner then the fact-finding technique should be employed immediately.

The "tools of the trade" for the fact-finding group is the basic standardization policy statement by management plus an analysis of the problem for valid and non-valid contentions in terms of the categories classified under theorem IV.

IV. SUCCESSFUL STANDARDIZATION DEPENDS ON VALID OR EFFECTIVE OPERATION UNDER FIVE CATEGORIES, NAMELY: PERSONNEL, PROFIT, POLICY, PROCEDURE, AND PSYCHOLOGY.

Personnel

(a) Standardization is a teamwork operation where success is more often assured through collective anonymity rather than individual stellar performance.

(b) Both administrative and technical abilities are essential attributes for standardization personnel.

(c) Incompetent or poorly trained participants can result in excessive waste and can experience delays.

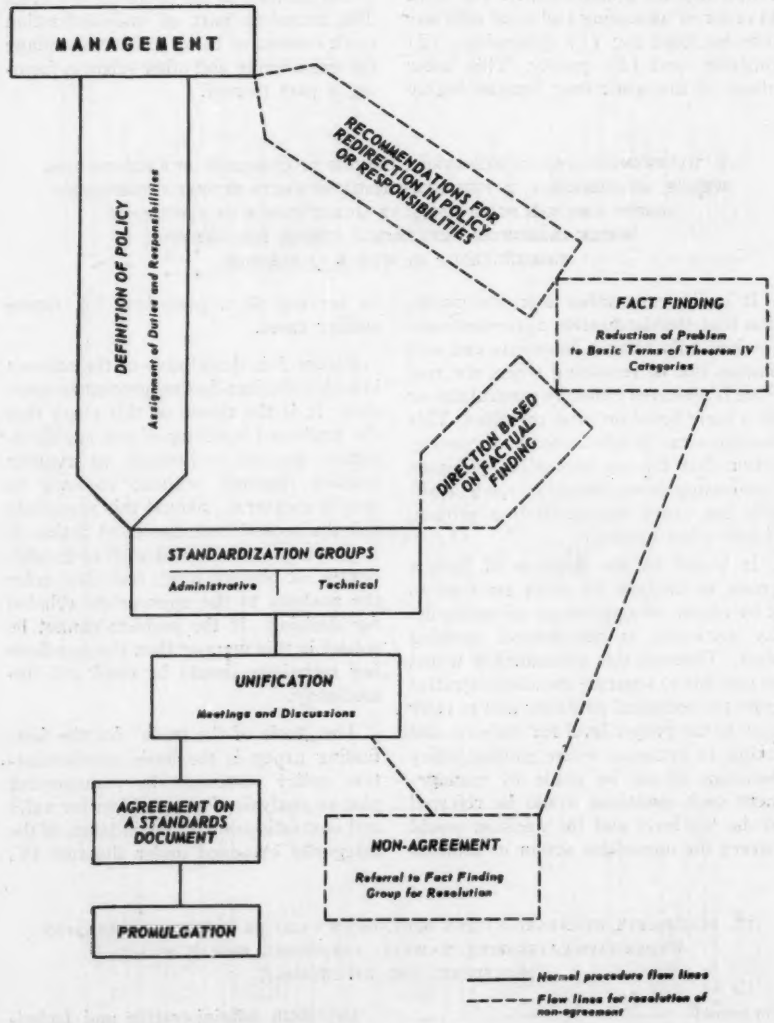


FIG. 3—Administrative and Technical Control of Standardization Effort.

(d) The human element in standardization must be fully recognized. The performance of an individual is the result of a number of factors which include: degree of judgment, rate of change of viewpoint, technical and administrative evaluation, prior commitments, past experience, working environment, personal reaction and evaluation of others, loyalty to parent organization, and many others.

Profit

(a) Sound and lasting standardization is achieved through the process of evolution rather than revolution. Progressive steps in standardization must be sufficiently small so as not to overturn or radically change the preceding step. Sufficient time must be allowed between each advancing step to permit consolidation of the latest position by general acceptance and use and thus make ready for the next advance.

(b) Research trends are indicative of forthcoming standardization and the initiation of standards projects before manufacturing tools and processes become fixed, can lead to tremendous ultimate savings in time and money.

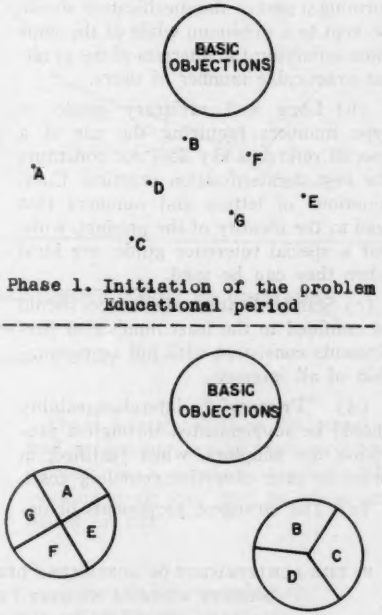
Policy

(a) Mandatory enforcement of a standard, will, in most cases, destroy the usefulness of the standard; the best policy is therefore voluntary agreement.

(b) Perfection is not necessary and cannot be attained in the first or any other issue of a standard. The first draft should be released as soon as it is generally workable with a planned revision schedule so that each successive draft represents an improvement. If this policy is not followed then it can be truly said that, "The best is the enemy of the good."

(c) Greatest availability should be assured by the elimination of restrictive proprietary and non-essential requirements.

(d) Standardization should not be attempted except in cases where there will be an eventual saving in time, money, manhours or space.



Phase 1. Initiation of the problem
Educational period

Phase 2. Crystalization of basic viewpoints

Phase 3. Final integrations of views
Standardization accomplished

FIG. 4—General Integration Sequence for Standardization.

(e) It is important to define the policy as to when either the performance or formulation type of specifications shall be used.

Procedure

(a) The types, grades and classes forming a part of the specification should be kept to a minimum while at the same time satisfying the interests of the greatest practicable number of users.

(b) Long and arbitrary grade or type numbers requiring the use of a special reference key does not constitute the best standardization practice. Combinations of letters and numbers that lead to the identity of the product, without a special reference guide, are ideal when they can be used.

(c) Standardization conferences should be confined to the least number of participants consistent with full representation of all interests.

(d) "Primary" * interchangeability should be supplemented through a provision for adaptors, when justified, in order to save excessive retooling costs.

(e) The strongest proponents of opposing views should be included in the membership of task or working committees.

Psychology

(a) Concession on minor points of disagreement, is advisable; it may bring major returns in the form of important concessions from the other side. What is major from one viewpoint may be minor from another.

(b) Good proposals leading to the elimination of a controversy should wait until inferior proposals are examined by a group during the earlier part of their deliberation. Otherwise the real value of the proposal may not be recognized and there is a big probability that it will be rejected.

(c) Participation in the development of a standard represents an investment. Use of the standard represents a return to the investor on his investment. Complete coordination during development of a standard is therefore invaluable.

(d) Continued discussion of a point after it has been settled may dissolve the agreement and may return the discussion to its initial unsettled stages.

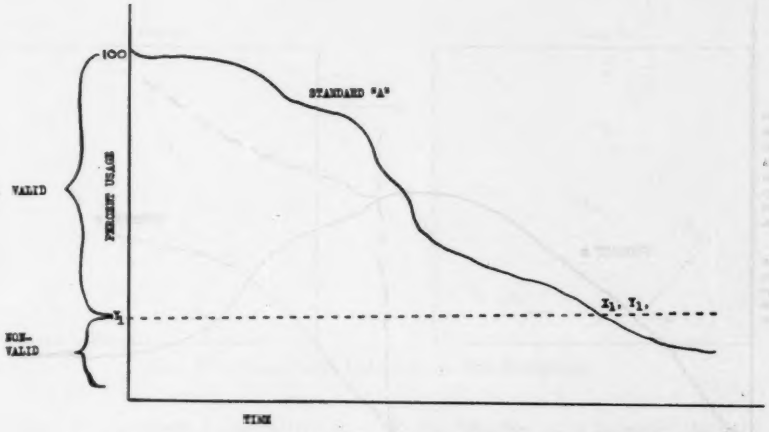
V. THE ACHIEVEMENT OF AGREEMENT DEPENDS ON THE "INTEGRATION OF VIEWS" CONCEPT WHERE A NUMBER (ANY NUMBER) OF SCHOOLS OF THOUGHT MUST BE REDUCED TO UNITY.

The initial stage of a discussion, on a subject that is being considered for the first time, represents the educational period. Questions are asked and answered concerning scope and objective. It is illustrated as phase 1 of Figure 4. The symbols "A," "B," and "C," etc., are indicative of individuals with different backgrounds, aims, and reactions. No apparent progress is made but the real progress is quite extensive if a logical and attractive presentation is made and all questions are satisfactorily and openly answered. This is the period when cooperation can be assured to a large degree. It is also the period which, if improperly handled, will witness the sowing of seeds of dissension.

Phase 2 of the work (see Fig. 4) has been reached when the number and kind of different viewpoints can be identified. It is the task of the standardization body to discover the reason for the differences and to seek compromise solutions that are compatible with the needs of all represented interests.

In case a deadlock ensues and no further progress appears probable in the near future, it is appropriate to refer the problem to the fact-finding group.

* Without the use of adaptors.



Y_1 = PERCENTAGE OF USE OF THE MOST VALID COMPETITIVE STANDARD. WHEN VALIDITY DROPS BELOW Y_1 STANDARD "A" MAY BE SAID TO BE INVALID.

FIG. 5—Standardization Validity Chart.

The findings of this group may be referred to management if a policy decision is needed; or the facts in clarified form may be referred back to the working committee for reconsideration.

Phase 3 of the work is the period of final agreement when all needs have been included in a common standard. The working draft may then be edited and issued for use.

VI. THE USEFULNESS AND LIFE OF A STANDARD ARE DETERMINED THROUGH THE FACTORS OF VALIDITY AND ECONOMIC STABILITY.

A standard is valid to the extent that it is used. Therefore if a single standard is the only one in use it has a validity of one hundred per cent. If, however, competitive standards are in use for the same thing then a validity subtractive factor is present. Validity might be expressed mathematically as Ta/Tp where Ta represents the total number of actual users and Tp is indicative of the total number of possible users.

Figure 5 illustrates validity in curve form. It will be observed from the curve that, under the definition we are using, standard "A" is no longer valid after it has dropped below point Y_1. The competitive standard having the greater usage would then be considered the valid one. A downward slope for the curve is indicative either of the need for revision or that its useful life is approaching an end.

Standardization is stabilized through capital investments in tooling, plant capacity, and processing. It is not economically feasible to radically change the standard before the existing set-up has been paid for and a reasonable profit has been returned. This introduces the element of economic stability which must be reckoned with.

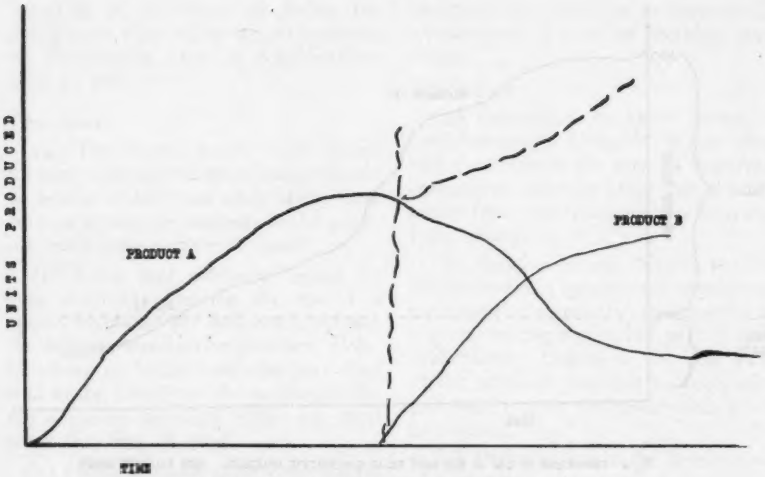


FIG. 6—Economic Stability Curve.

Through evolutionary changes in an art it is inevitable that the economic stability of an unchanged standard should deteriorate and that a new standard should take its place. This is shown in Figure 6.

In the curve the subtractive influence of product "B" is beginning to be felt. The dotted portion of the curve for product "A" indicates continuing usefulness of the original standard through revision to include additional necessary types. This is in keeping with a proper policy of dynamic standardization.

VII. CONTINUING VALIDITY PROBABILITY IS A FUNCTION OF, AND PROPORTIONAL TO, THE GEOGRAPHICAL SEPARATION OF THE DIFFERENT PRODUCERS AND USERS.

A high degree of validity in a standard is the result of thorough coordination among the users of the standard. It is, in essence, dependent on the coordination factor. The factor continues at a high level only through increased effort as the distance between the points of interest increases. The ability to interchange ideas on an understandable basis and to resolve differences is much more difficult and validity of the standard is thereby endangered.

The space separation idea is set forth in Figure 7 where "S" may specifically represent a standard for a hose fitting with the subscript indicating interchangeability or non-interchangeability of the different couplings. The distance "d" is the separation between the areas of standardization. Analysis of this set of conditions leads to several general conclusions, namely:

(a) The preponderance of use of the S_1 standard occurs in area A and consequently the demand on producing facilities, where there are producers in the areas, will commit the manufacturing investment to tooling for the production of standard S_1.

(b) The same condition regarding S_3 exists in area B as for S_1 in area A.

(c) The appearance of standard S_1

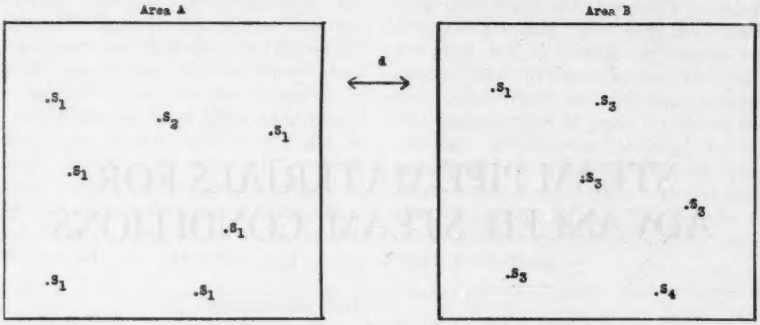


FIG. 7—Geographical Influence on Standardization.

in area B represents a subtractive influence on standard S_3 where the greatest common usage is in favor of S_3.

(d) The presence of standard S_1 in area B represents potential validity increase for standard S_1.

The distance "d" acts as a retardant to the adoption of a common standard but in time, assuming that legitimate reasons exist for the differences in the standards, there will be developed a common standard containing a minimum number of types but still adequate for use by all.

CONCLUSION

In summarization and conclusion the original question: "Is Standardization a Science?" should now be answered. It can be concluded from the discussion that:

(a) Successful standardization depends on the skillful use of the pertinent rules forming a part of the sciences of Psychology, Engineering, Management, and Economics. Proper standardization is therefore a science comprised of several other sciences.

(b) Definite rules or theorems govern standardization and when these rules are observed the reproducible results, inherently a part of every science, can be achieved.

(c) Standardization is not a science unless the conditions "a" and "b" above have been met. Random approaches, neglect of fact-finding techniques, and violation of the basic principles leading to agreement transforms standardization from a science that may be practiced by many to an art that is known by few.

STEAM PIPE MATERIALS FOR ADVANCED STEAM CONDITIONS

ACKNOWLEDGMENT

This article consists of extracts from a paper read before The Institute of Marine Engineers on 13 May 1952. Its author is D. W. CRANCHER of the British Shipbuilding Research Association. The abridged article was published in the 1952 Annual Steam Number of "The Marine Engineer and Naval Architect."

The upper limits of steam conditions recommended by Brown, Cook and Gardner for modern steam turbine plant are shown in Fig. 1 and these are in fair agreement with the suggested range of steam conditions, based on American practice, given by Ireland, Semar and Mochel at the recent International Conference of Naval Architects and Marine Engineers. It appears from their recommendations and from modern land power station practice that in the near future most marine turbine machinery will probably operate within the temperature range 800-950 deg. F. with a few possible experimental installations employing very advanced temperatures up to 1050 deg. F. At these higher steam temperatures, plain carbon steel, which has proved excellent for the lower conditions, rapidly deteriorates in strength and, if inordinately thick pipes are to be avoided, alloys of greater strength will have to be used.

In considering suitable alloys attention should be fixed mainly upon resistance to creep and corrosion, stability of the microstructure, suitability for manufacture into a hot finished or cold drawn seamless tube, mechanical properties at room temperatures, ease of fabrication, availability and cost. In addition to these general points the engineer is also concerned with the margin of safety in respect to temperature, the amount of permissible distortion during the working life of the component and the determination of safe working stress.

At the steam temperatures and pressures envisaged for future installations (above 850 deg. F.), the steam pipe

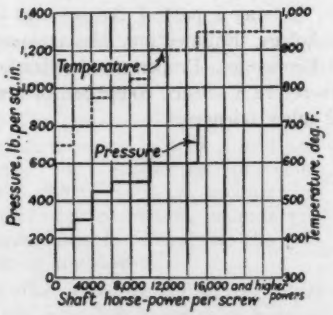


Fig. 1—Suggested limits of steam conditions for marine steam turbines

material would be operating under conditions when creep becomes of practical importance so that the distribution of stress across the section based upon elastic theory and the determination of a safe working stress from conventional short term tensile tests would not be valid. Steam pipe materials working under such conditions should therefore possess adequate resistance to creep but the choice of such materials is limited because of the extensive and costly long-term creep tests necessary to establish this property. Not only must each test last for thousands of hours but several tests on the same material must run concurrently at different stresses and temperatures in order to obtain the complete information required to fix safe working stresses for different operating temperatures. As a result of such tests, the following four basic types of alloys are now well established for steam pipes, these being:—

(i) Low carbon steel

(ii) Steels containing molybdenum.
- C, 0.1-0.15 percent
- Mo, 0.3-0.7 "

(iii) Steels containing molybdenum and chromium.
- C, 0.07-0.17 percent
- Mo, 0.40-0.8 "
- Cr, 0.60-1.20 "

N.B. 0.75 per cent silicon is sometimes added to this alloy

(iv) Steels containing molybdenum and vanadium.
- C, 0.1-0.15 percent
- Mo, 0.5-0.65 "
- V, 0.25-0.3 "

In addition to these well-established ferritic steels, an austenitic steel of the 18 percent chromium, 8 percent nickel type is now being used, mainly in America but also to some extent in this country, for use at high temperatures in the region of 1050 deg. F.

PLAIN CARBON AND 0.5 PERCENT MOLYBDENUM STEELS

Excellent reports on the creep properties of both plain carbon steel and 0.5 percent molybdenum steel have been given by Tapsell, in each case the material tested being taken from an actual steam pipe. The analysis and manufacturing details of the plain carbon steel sample, which comply with Lloyd's Register's material specification for steam pipes are given in Table I.

Molybdenum is one of the most important alloying additions for improving the creep properties of steel and molybdenum steels have been used for high temperature service for about twenty years now.

As with plain carbon steel, Tapsell and Ridley carried out a series of creep tests on samples of 0.5 percent molybdenum steel taken from an actual steam pipe, the analysis and manufacturing details of which are shown in Table II. The tests were made at 1, 2, 4 and 6 tons per sq. in. and, at each stress, tests were carried out at several temperatures up to 0.5 percent creep. In this way sufficient data were obtained to establish stress temperature relationships from 0.1 to 0.5 percent creep in 100,000 hours; curves f[illegible].1, 0.3 and 0.5 percent creep have l[illegible] constructed from this published data and are shown in Figs. 2, 3 and 4.

An examination of the curves shown in Figs. 2, 3 and 4 for 0.5 percent molybdenum steel shows that there is a

Approximate dimension	Process	Method of deoxidation	Condition as supplied	Chemical composition								U.T.S. tons per sq. in.	Micro-structure
				C	Si	S	P	Mn	C	Ni	Mo		

TABLE I—PARTICULARS OF PLAIN CARBON STEEL PIPE

10½ in. O/D ½ in. wall thickness	Basic open-hearth	Fe-Mn to bath Aluminum "Alsifer" in ladle	Hot rolled	0.135	0.18	0.037	0.028	0.47	Nil	Nil	Nil	26.5	Typical of hot-worked tube, contains nuerous fine non-metallic inclusions

TABLE II—PARTICULARS OF 0.5 PER CENT MOLYBDENUM STEEL PIPE

13 in. O/D 1.95 in. wall thickness	Acid open-hearth	Si-Mn + Fe-Si before tapping Aluminum after tapping	Normalized at 900 deg. C. (1,652 deg. F.)	0.09	0.22	0.034	0.023	0.52	0.08	0.26	0.50	27.0	Coarse ferrite Compact pearlite.

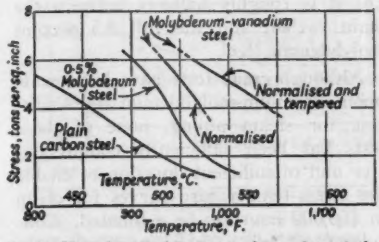


Fig. 3—Stress-temperature curves for various steels giving 0·1 per cent. creep in 100,000 hours

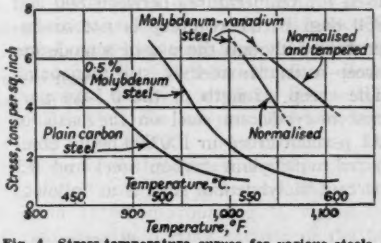


Fig. 4—Stress-temperature curves for various steels giving 0·5 per cent. creep in 100,000 hours

rapid fall of strength in this material as the temperature increases—between 900 and 975 deg. F., for example, there is a drop in strength from 6 to 2 tons per sq. in. based on 0.1 percent creep in 100,000 hours. Up to 925 deg. F., however, the rapid deterioration in this material will not be serious and at 900 deg. F. it will carry roughly twice the stress of plain carbon steel on a basis of 0.1 percent creep in 100,000 hours. Beyond 925 deg. F., the stress-temperature curves become very steep and the material decreases in strength rapidly. The margin of temperature between creep strains of 0.1 and 0.5 percent in 100,000 hours is 30 Fahrenheit degrees at 6 tons per sq. in., and 20 Fahrenheit degrees at 4 tons per sq. in. In view of the low elongation at rupture after long term creep associated with this material, these temperature margins are very important. This point is discussed in greater detail elsewhere but it should be mentioned here that it may be unsafe to exceed a creep strain of 0.5 percent in 100,000 hours with 0.5 percent molybdenum steel. In view of the possibility arising from inadequate superheat control of heating for lengthy periods in excess of the working temperature, the margin of temperature between the permissible design creep strain, say, 0.3 percent in 100,000 hours and 0.5 percent creep in 100,000 hours, should be noted.

The 0.5 percent molybdenum steel discussed above is the standard alloy of this type but an alloy containing 0.3 to 0.4 percent molybdenum is sometimes

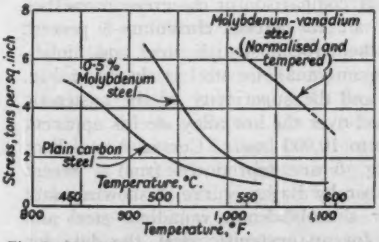


Fig. 3—Stress-temperature curves for various steels giving 0·3 per cent. creep in 100,000 hours

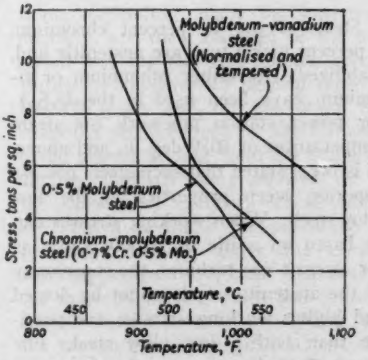


Fig. 5—Stress-temperature curves for various steels to rupture in 100,000 hours

used for temperatures between 800 and 850 deg. F. where creep is not so important, although the use of a moderate creep-resistant steel is still beneficial. The creep strength of the 0.3-0.4 per cent molybdenum steel on the basis of 0.1 percent creep in 100,000 hours compared with plain carbon steel and 0.5 percent molybdenum steel is as follows:

	lb. per sq. in 850 deg. F.	900 deg. F.
Plain carbon	9,400	6,400
0.3-0.4 per cent molybdenum steel	13,000	9,000
0.5 per cent molybdenum steel	15,500	13,000

i.e., it is roughly halfway between the plain carbon and the full 0.5 percent molybdenum steel.

Although creep tests have been made upon chromium-molybdenum steels suitable for steam piping, none of these tests has been sufficiently comprehensive and of sufficient duration to enable the stress-temperature curves for creep in 100,000 hours to be estimated. Considerations other than creep strength, favor a chromium addition to 0.5 molybdenum steel for high temperature steam service as this effects an increase in creep ductility and resistance to graphitization.

MOLYBDENUM-VANADIUM STEEL

The addition of vanadium to 0.5 percent molybdenum steel results in an alloy possessing excellent creep properties which have been investigated by Glen who, after an extensive series of tests, established sufficient data to enable the stress-temperature characteristics to be determined for creep strains of 0.1 to 0.5 percent in 100,000 hours.

Further evidence on the excellent creep properties of this steel has recently been given by Glen who states that test specimens at 1022 deg. F., loaded at 6 tons per sq. in., were unbroken after 90,000 hours with the corresponding extension less than 1 percent. The optimum creep properties of this steel are dependent upon the subsequent tempering heat treatment given to the normalized steel and, with heat treatment, molybdenum-vanadium steel should provide sufficient resistance to creep to allow for operating temperatures up to 1050 deg. F.

AUSTENITIC STEEL

Steels of the 18 percent chromium, 8 percent nickel type are austenitic and, stabilized with either columbium or titanium, have been used in the U.S.A. for power station pipework for steam temperatures of 1050 deg. F. and above. It is often stated that such steels possess superior creep properties to the low alloy steels. When working stresses can be based on a life of 10,000 hours, as for aircraft gas turbines, the superiority of the austenitic steel cannot be denied and higher working stresses are possible than with a low alloy steel. For steam plant, however, working stresses must be based on a much longer life, usually 100,000 hours, and the maintenance of the superiority possessed by austenitic steels up to 10,000 hours cannot be assumed.

A comparison of the creep properties of an 18 percent chromium-8 percent nickel type austenitic steel and molybdenum-vanadium steel is shown in Fig. 6 and the superiority of the austenitic steel over the low alloy steel is apparent up to 10,000 hours. Curves A and B of Fig. 6 are reproduced from a recent paper by Bailey, curve A showing data for a molybdenum-vanadium steel and B for an austenitic steel, the data for which were from Kirby and Sykes. By

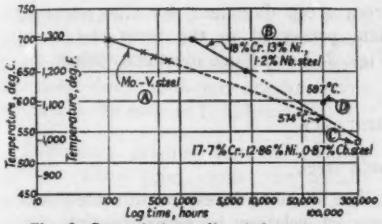


Fig. 6—Creep test results at 3 tons per sq. in. stress and 0·3 per cent. creep strain for molybdenum-vanadium and austenitic steels

extensive extrapolations of the experimental data (shown dotted), Bailey concluded that at 100,000 hours the creep properties were virtually the same for both steels and that there was no justification for supposing that austenitic steel was superior to molybdenum-vanadium for high temperature steam service. Bailey's straight line extrapolation of the molybdenum-vanadium steel probably underestimates the strength of this material and an extrapolation following a curved line to the point D, taken from Fig. 3, would appear to give a truer picture of the behavior of this material. This modified extrapolation, however, will add strength to Bailey's conclusion. The present position is that there is a lack of conclusive published data supporting the claims for the long-life strength of austenitic steel. Further information is needed to clarify the position.

DETERMINATION OF SAFE WORKING STRESS AND PIPE THICKNESS

In this country, there are, at present, no standard regulations governing the thickness of alloy steel steam piping for merchant ships, although there are standards for the scantlings of 0.5 percent molybdenum and 0.5 percent molybdenum — 1 percent chromium piping for Naval vessels. A survey of American standards governing the thickness of alloy steel piping has been given by Meyer and the American Bureau of Shipping has published recommendations for the thickness of steam piping for working temperatures up to 1050 deg. F.

The direct calculation of pipe thicknesses is a difficult matter when creep conditions prevail, as the equations based on elastic theory (Lamé equation) no longer hold owing to the relaxation of the stresses. In a notable paper, however, Bailey has recently given a method of determining the thickness of steam piping working in the creep condition, simple formulas being derived, based upon safe working stresses determined from long-term creep tests. In determining safe working stresses for use in Bailey's formulas, both the creep-resisting properties and the creep-rupture characteristics must be examined. Three possible cases arise, viz., materials possessing high creep ductility such as mild steel, those possessing moderate ductility such as molybdenum-vanadium steel and brittle alloys such as 0.5 percent molybdenum steel. Maximum permissible elongations, depending upon its long-term ductility, are then assigned to the material, and for the very ductile metals Bailey recommends 0.5 percent creep in 100,000 hours and for the other two cases 0.3 percent creep in 100,000 hours —the benefit arising from the moderate ductile materials being allowed for in the subsequent analysis. These values are chosen to allow for possibility of prolonged heating above the normal working temperature, local weakness in the material arising from lack of uniformity in the material or welding, and the prevention of the material entering the tertiary stage of creep with its accompanying intercrystalline cracking.

Once the maximum permissible elongation in 100,000 hours has been fixed, the safe working stress can be found from creep data and, for this purpose, data presented in the form shown in Figs. 2, 3 and 4 are most convenient.

CORROSION RESISTANCE

The maximum operating temperature at which ferritic alloys, such as molybdenum-vanadium steel, can be used for steam pipe service is largely determined by their resistance to internal corrosion under the action of steam.

Except for one very extensive series of tests carried out by Rohrig, Van Duzer and Fellows, very little information has been published on the long-term corrosion behavior of steel in steam. The tests of Rohrig have provided relevant data covering plain carbon, low alloy and austenitic steels. Smooth-finished, cylindrical test pieces were placed in a steam pipe and the testing was carried out under actual steaming conditions at 925 deg. F. and 1100 deg. F. Weight loss and thickness of scale penetration were measured after tests of long duration, some of which extended to 15,000 hours. No appreciable corrosion was found in any of the steels tested at 925 deg. F., but at 1100 deg. F. the steels were attacked in varying degrees. Plain carbon steel is the most severely attacked. Low alloy steels, which appear to act as a group, come next, and austenitic and stainless steels come last, showing negligible attack. The tests on the low alloy steels very surprisingly failed to reveal any improvement in the corrosion resistance of steels containing up to 5 percent chromium, and a steel containing 5 percent chromium showed no appreciable difference from a 0.5 percent molybdenum steel.

The shape of the curves of scale thickness in relation to exposure time for low alloy steel indicates that the rate of scale penetration diminishes with time; an extrapolation of these data to 100,000 hours should therefore give a fairly reliable indication of the order of the scale thickness to be expected over the life of the plant at 1100 deg. F. The scale thickness of these steels seems to be about 10-15 thousands of an inch in 100,000 hours, which is not of great significance. Unfortunately a molybdenum-vanadium steel of the type used for high temperature steam service was not included in the tests; however, one of the steels which were tested did contain 0.18 percent vanadium, which indicates that vanadium is not harmful. Moreover the scaling in air of 0.5 percent molybdenum—0.265 percent vanadium steel appears similar to that of 0.5 percent molybdenum steel, and it therefore appears safe to assume that molybdenum-vanadium steel possesses the same long-term corrosion characteristics as the low alloy steels tested, and that up to 1100 deg. F. it would not show any significant scaling in steam during 100,000 hours. This conclusion is important as it shows that ferritic steels can be considered for steam pipe service up to 1100 deg. F. so that 1050 deg. F., which is generally held to be the safe limit of these steels, is possibly a conservative figure.

WELDING AND FABRICATION

The site-welding of sections of the steam-pipe line together, a practice which is now widely used for land installations, has not yet been advocated for marine installations in this country but the trend towards higher steam conditions may require this to be done in the future, to at least part of the line.

The question of the welding of steam pipe materials is still of great importance, even when flanged connections are used, since the flanges are commonly welded to the ends of the pipe.

Difficulties arising from the welding of low alloy pipe steels are usually caused by lack of experience in the correct welding procedure and the necessary heat treatment, since no serious metallurgical problems are involved apart from graphitization, which has already been discussed. Both electric-arc and oxy-acetylene welding are used, though the latter is usually restricted to pipes up to about 4 in. in diameter. For welding the low alloy steels discussed in this paper by the electric-arc process, the electrodes should be of similar composition to the parent metal although for welding 1 percent chromium—0.5 percent molybdenum steel a plain 0.5 percent molybdenum steel electrode can be used since weld deposits are comparatively free from graphitizing tendencies.

Both preheat and postheat treatment are now generally specified for steam-pipe welds in low alloy and plain carbon steel for use in advanced steam conditions. Preheating is used in order to prevent basal cracking and for plain carbon steel, 0.5 percent molybdenum steel and 1 percent chromium—0.5 percent molybdenum steel a minimum temperature of about 200 deg. C. (482 deg. F.) is generally advised; for molybdenum-vanadium steel a minimum temperature of 250 deg. F. is advocated, although there is a fairly wide permissible margin above these temperatures. Postheat treatment will depend upon the type of weld; if an oxy-acetylene weld, then a normalizing treatment should be given in order to refine the overheated structure resulting from this method of welding. As a rule, molybdenum-vanadium steel is not welded by this method, but for the other low alloy steels discussed in this paper the normalizing temperature will be in the range 900-950 deg. C. (1652-1742 deg. F.), for which a gas muffle furnace can be used. Welds made by the electric-arc process have a finer grain structure than those made by oxy-acetylene owing to the quenching action of the cooler parent metal. As a result, normalizing is not considered essential and a stress-relieving treatment is usually recommended instead. There is convincing evidence that the removal of internal stress greatly reduces the possibility of brittle fracture in the welded zone and this is a consideration of great importance for marine work in view of the chances of thermal shock due to water passing into the hot pipe-line when the ship is in a heavy sea.

The internal stresses set up by welding are relieved by creep relaxation, longer heating time being needed than for normalizing. It is unwise, however, to exceed the stipulated times for stress relieving, since there is the danger of damaging the creep properties from spheroidization. For the same reason, stress-relieving temperatures should be accurately maintained and for plain carbon steel, 0.5 percent molybdenum steel and 1 percent chromium—0.5 percent molybdenum steel, the temperature generally recommended is in the range 600-650 deg. C. (1112-1202 deg. F.). Molybdenum-vanadium steel is more stable than the other low alloy steels and can stand a higher stress-relieving temperature, usually up to 700 deg. C. (1292 deg. F.).

The welding of austenitic steel requires a different procedure from that described above, the outstanding difficulty arising when a joint is to be made between austenitic and ferritic steel. This problem has already been given considerable attention in the U.S.A. and is now being faced in this country although a satisfactory solution has yet to be found. When the two sections to be welded together are both austenitic, the

difficulties are not so great and electric-arc welding using austenitic steel electrodes can give a sound weld. Rapid cooling or quenching of austenite merely softens it and for this reason both preheat and postheat treatments of austenitic steel welds are generally considered unnecessary; in fact, it is common practice in the U.S.A. to water cool the joint during welding. Welding difficulties do arise, however, and these are principally micro-cracking (the reason for which is still uncertain) and the formation of excessive sigma, which apparently can be controlled by careful selection of electrode composition.

UNITED STATES PRACTICE

Broadly speaking, the steam conditions used in the United States marine machinery are higher than in Great Britain, the highest steam temperature in American marine service being 1020 deg. F., and it is of interest, therefore, to review briefly the steam pipe materials favored. A wider range of materials is used than in this country, although the main alloying elements appear to be restricted to chromium and molybdenum. There are indications, however, that within recent years molybdenum-vanadium steel is being adopted for some American land power stations, operating at high temperatures. Modern United States practice appears to take the following trend:—

Up to 775 deg. F.....	Plain carbon steel.
775 to 875 deg. F.....	0.5 percent molybdenum steel.
875 to 950 deg. F.....	1 percent chromium—0.5 percent molybdenum.
950 to 1,000 deg. F.....	1.25 percent chromium—0.5 percent molybdenum steel.
975 to 1,050 deg. F.....	2.25 percent chromium—1 percent molybdenum steel.
1,050 to 1,100 deg. F.....	18-8, columbium stabilized austenitic steel.

It should be noted that there will most probably be some variation in the given temperature ranges.

It is evident from this list that American engineers attach great importance to chromium in their high temperature steels and there is a widespread opinion that a steady increase in the chromium content results in a correspondingly steady improvement in scaling resistance. The work of Rohrig and his colleagues, already referred to, throws considerable doubt on this belief and from their work it appears that chromium additions have to be of the order of 9 or 10 percent before there is any significant improvement in the scaling resistance of low alloy steels. Furthermore, it is doubtful whether chromium additions above 1 percent improve the creep properties of low alloy steels. Considering the fairly extensive graphitization troubles experienced in the United States and the discovery that the remedy for this lies in the use of chromium, the development of the range of low alloy chromium-molybdenum steels in that country is understandable.

PROGRESS ON NAVAL USE OF REINFORCED PLASTIC PIPING

ALLAN M. MCKENZIE AND H. J. STARK

THE AUTHORS

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MR. H. J. STARK graduated from Lawrence College of Wisconsin in 1933 and holds a Bachelor of Arts degree. From 1935-36 he pursued graduate work in Chemistry at George Washington University, Washington, D. C., and was employed as a research and analytical chemist at the Naval Research Laboratory, Anacostia, D. C., from 1937 to 1940. He entered Military Service with the Army Air Forces in 1940, serving in the New Guinea, Leyte, and Luzon Campaigns in the Southwest Pacific area. Upon returning to civilian life in 1946 he continued his civilian scientific pursuits for the Navy Department in the plastics section, Research Division, of the Bureau of Ships, where he is now employed as a Materials Engineer. He is a member of American Society of Naval Engineers, Society of Plastic Engineers, Association of Senior Engineers of the Bureau of Ships, Alpha Chi Sigma, Kappa Kappa Psi, Horological Institute of America, Washington Rubber Group, and Reserve Officers Association of America.

INTRODUCTION

The publicity given to the satisfactory use of reinforced, thermosetting-resin plastic piping on a Navy destroyer escort has evoked widespread interest on the part of the plastics industry, piping manufacturers and marine organizations. It is desirable therefore to summarize in a single place the considerable information accumulated on naval development and use of reinforced plastic piping. Progress to date reported herein is the result of contributions by numerous individuals in the naval establishment and cooperating industrial concerns. These developments up to April 1952 represent the initial steps of an industry still in an early stage.

PLASTIC PIPING

INITIATION OF DEVELOPMENT

In the period after World War II when experience with naval shipboard piping was being reviewed, salt water piping systems received much attention. This was because the most satisfactory tubing, copper-nickel (70:30) alloy, had not been available in the required quantities during this period. Furthermore, both copper-nickel and its non-ferrous and ferrous substitutes required excessive maintenance due to corrosion-erosion failures. The present first choice for salt water piping, copper-nickel (70:30) alloy with high iron content, has shown improved performance, but unfortunately its nickel constituent makes it one of several critical alloys in short supply. Chemical resistance of plastics and the advances in their use during the war indicated that plastic piping should be thoroughly investigated. Combustibility and fabrication limitations, particularly fittings, were recognized as disadvantages to be weighed against advantages of excellent corrosion-erosion resistance, weight savings, and plentiful supply of the raw materials. In June 1947, after a survey of industrial concerns capable of research and development in plastics fabrication, the United States Plywood Corporation was selected to develop and evaluate plastic piping for naval shipboard use.

UNITED STATES PLYWOOD CORPORATION'S RESULTS

The United States Plywood Corporation investigated glass fiber reinforced thermosetting polyester resin plastic piping. Their principal conclusions upon completion of the work in May 1949 were briefly as follows:

Corrosion-erosion and fouling tests

Extensive jet impingement and rotating disc tests show that plastic material is completely resistant to the corrosion-erosion effects of sea water under low and high velocity flow. Most metals and alloys when tested for comparable purposes showed much erosion. The material offers little resistance to bio-fouling. The marine boring type of organisms cause no damage.

Preliminary flammability and heat tests

Bunsen burner flame tests on sheet material following standard procedures indicate that the polyester resins are of two types; a high heat-resistant type and a self-extinguishing type having slightly inferior heat-resistance. The phenolic resins combine high heat-resisting and self-extinguishing properties. However, jet impingement, rotating disc tests and long time immersion tests showed phenolic fibrous glass laminates to be inferior to the polyester-glass laminates. By coating polyester-glass piping externally with Albi—"R" Formulation No. 777, a fire-resistant paint of the intumescent type, the high heat-resistant polyester resins may be used and offer good resistance to flame attack in a fire. This combination is recommended as the best solution to meet the requirements of heat and fire resistance.

Simulated fire tests (hot air)

In extensive tests, plastic tubes were subjected to both internal pressure and external heat to determine the relationship of heat resistance, pressure and time. Tubes used were 2¼ in. O.D., 2 in. I.D. and 26 in. long. Selectron 5016 was found to have the best heat resistance. The short-time (8 hours) tests indicate that tubes made with this resin could be used at a maximum ambient temperature of 275°F. with an internal nitrogen pressure of 450 p.s.i. and at 425° with 150 p.s.i. nitrogen pressure.

This was also based upon an 8-hour test which produced no leakage or other failure.

Ignition and burning tests

Polyester resins, and low pressure phenolic resins with various types of glass cloth in laminated form were tested to determine their resistance to burning, burning characteristics and ignition temperature. Gaseous products of combustion were also determined. The phenolic resins resisted burning longer and when ignited burned for shorter times than the polyester resins. The polyester resins, although exhibiting somewhat less desirable ignition and burning characteristics excelled in other features; satisfactory high strength, water-resistant tubes could be prepared from these resins. This was more difficult with low pressure phenolic resins. Polyester resins ignited with flame at 670°F. to 850°F; without flame (self-ignition) within 836°F to 910° F. Carbon monoxide is the chief gas of toxicological significance produced when either polyester or phenolic resin is burned.

Materials investigation

It was found that eight-harness weave fiber-glass cloth was most suitable for making plastic tubing. Unidirectional-yarn fibrous glass tapes are also recommended for spiral-wrapping techniques. Despite many attempts, satisfactory low pressure phenolic resin-glass tubes could not be made. This was attributed to volatiles being given off during curing and causing porosity in the tube.

Design data

Hydrostatic tests of the plastic tubes show 15,000 p.s.i. to be the minimum hoop stress at which leakage occurs in tubes below 1½ in. I.D. Above this size the minimum leakage stress is 20,000 p.s.i. These values should be divided by a factor of safety of at least three for most conditions. Tees leaked at a minimum pressure of 600 p.s.i. and elbows at 1000 p.s.i. Leakage in fittings was through the joints and it is believed that pressure ratings could be increased by adding reinforcing hubs at the ends.

Development of Fabrication methods for tubing

Two basic methods were developed for making tubing. The first, which was used throughout most of this development program, consisted of convolutely wrapping glass cloth on aluminum mandrels and curing with heat from the inside out without pressure. This method is satisfactory for limited production. The second method consists of spirally wrapping unidirectional tape on the mandrel, cross-laminating at the optimum angle to obtain the most efficient strength properties. This method, developed only through prototype stages, is the one recommended for high production and low-cost manufacture of plastic tubing. With both methods it was necessary to develop carefully controlled impregnation and wrapping techniques together with controlled curing to obtain non-porous tubes.

Development of fabrication methods for fittings

The greatest effort was spent on the development of methods for making fittings and it was only after numerous variations of these methods that a successful one was found. It consists of wrapping templated dry glass cloth on a solid male form, placing the wrapped part in a split female mold, and injecting resin under air pressure. Cure is effected without heat or pressure by a special combination of catalyst and room temperature curing agent. Most satisfactory resins used were Marco MR-29C and Laminac 4128.

Development of joints

Two designs of permanent joints were developed. The first was a screwed connection with a modified acme tapered

thread bonded with polyester resin at the time of assembly. The second was similar but threadless. Two methods for machining joints were developed. One was by grinding with an abrasive wheel. The other was machining with a high-speed tungsten-carbide tool which is initially expensive but does not require frequent reshaping as does the abrasive wheel.

General

Within a period of less than two years a completely new product was developed. Its advantages include complete corrosion-erosion resistance and the highest bursting strength-weight ratio of known piping materials. Although more development of high-production techniques is required, the practicability of plastic piping has been demonstrated.

LARGE-SCALE CORROSION-EROSION TESTS

Approximately 42 ft. of plastic tubing, six 90 degree elbows and two tees were delivered by U.S. Plywood Corporation as partial fulfillment of their contract. The tubing had 2⅜ in. O.D. and 2 in. I.D. One-half of this quantity was made with Selectron 5016, a heat-resistant polyester, and one-half with Selectron 5041, a self-extinguishing but less heat-resistant polyester. The material was submitted to the U.S. Naval Engineering Experiment Station which made up a piping assembly at the Kure Beach Testing Station (Figure 1). Natural sea water was pumped through the system continuously, except during pump or power failures, for about 18 months. The velocity was high, at approximately

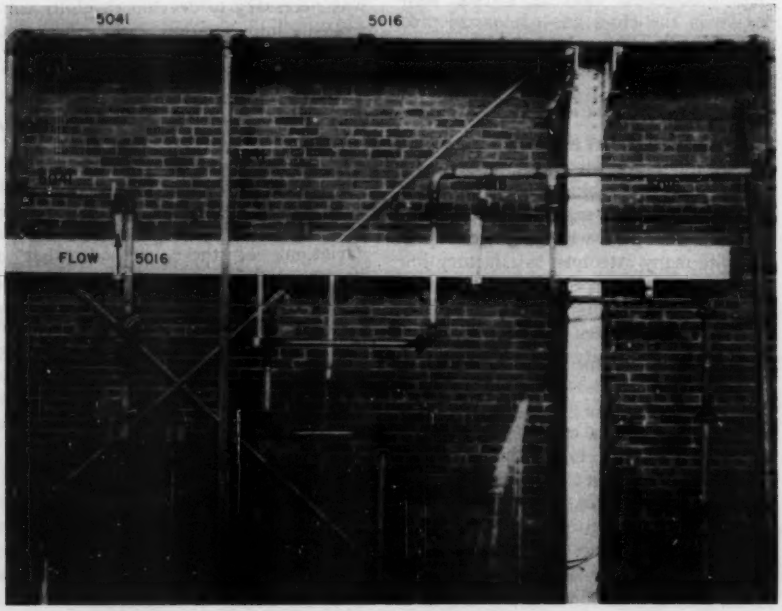

FIG. 1—Plastic Piping System at Kure Beach.

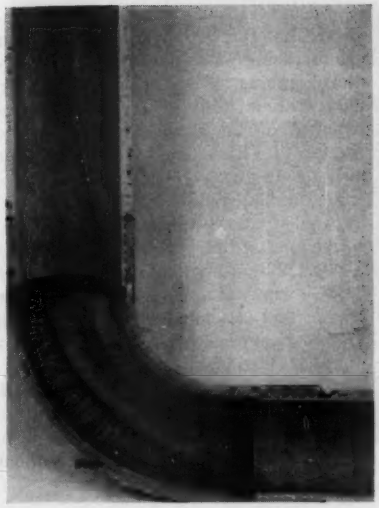

FIG. 2—Interior Surface of Plastic Piping After Test for 18 Months at 15 F.P.S. in Sea Water.

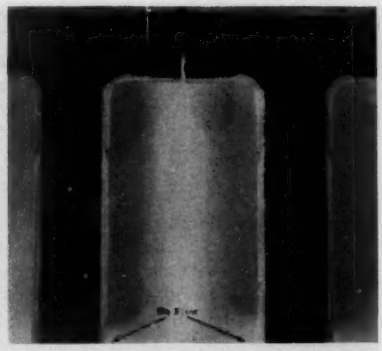

FIG. 3—Interior Surface of Plastic Tee and Portion of Dead-end Pipe Showing Marine Fouling.

15 ft. per sec. After this period of testing, there was no visible evidence of corrosion-erosion or other deterioration. Surfaces were smooth and not noticeably different than untested tubing (Figure 2). The system included a 10 ft. long, dead-end line branching from a plastic tee. Considerable marine fouling had accumulated in the dead-end line just below the tee (Figure 3). The remainder of the system was clean. The plastic material affords no resistance to fouling which may occur in most piping where such conditions as velocity and temperature are favorable to its growth. The materials have shown no evidence of damage from the attachment of marine organisms and no evidence of attack by marine borers. Flexural strength tests were made on specimens cut from both unused and sea-water-tested tubes. Material which had been exposed to sea water for 18 months had about 30.7% less strength. More recently developed sizings designed to produce better adhesion of resins to glass cloth are expected to minimize this effect.

ADHESIVE BONDED JOINTS

It was evident during assembly of the system at Kure Beach that threaded connections would not be practical for shipboard piping. The rigidity of the plastic material fixed the distance to which one piece could be screwed into another so that there was no opportunity to turn a tight connection into any desired position. The plastic tubing could not be bent or formed after manufacture.

An investigation of sleeve-type joints, using adhesive bonding without threads or tapered surfaces, was conducted by the U.S. Naval Engineering Experiment Station. Joints were prepared by machining 2 in. tubes with male and female ends to provide 1½ in. lap. The female part only was cut with shallow internal spiral grooves. A ⅛ in. hole was drilled through the wall to permit injection of resin into the groove by a lever-type, hand grease gun. Based on shear strength and ease of hand assembly, the optimum radial clearance was found to

be 0.003 in. Bonding resins used were Marco MR-28C and Marcokit No. 249 which cure at room temperature. Joints developed shear strengths from 670 to 1170 p.s.i. which was considered low but adequate. Leakage occurred at hydrostatic pressures of 1250 p.s.i. or higher through the undercut section of the female part. Effective joints were made with a grooved and sandblasted steel male section and a plastic female section bonded with room temperature curing MR-28C resin. Consistent shear strengths of 850 to 950 p.s.i. were obtained.

The Engineering Experiment Station made several more tests to develop the plastic piping joint. Alemite #1792, ¼ in. 28 thread hydraulic type fittings with ball checks were used to improve injection of bonding resin. Joints were "gunned" satisfactorily when grease fittings were located on top or at sides of connections. Injection from the bottom did not properly fill the annular space and distribute the resin.

Tests were made of plastic tubing bonded with Marcokit #249 resin to cast-bronze pipe couplings. Shear strength obtained was 600 p.s.i. and joints did not leak when subjected to hydraulic shock of 0 to 940 p.s.i. in ⅛ second.

A method for repair of minor leaks was devised. The area of the leak was cleaned and roughened. It was then painted with Marco MR-28C resin and tightly wrapped with glass tape impregnated with resin. Repairs held 650 p.s.i. hydrostatic pressure.

Mechanical-shock tests were conducted to compare resin bonded-joint plastic tubing with flanged-joint, copper-nickel tubing. Test specimens 10 ft. long with a joint at the center were mounted on the shock-test table of the Station's high-impact shock machine for medium-weight equipment. The machine simulates shipboard shock caused by underwater explosions. It is described in Military Specification MIL-S-901. The direction of the hammer blow is upward to the anvil under the table. Test assemblies were supported by two hangers spaced 6 ft. apart. Piping was filled with water at 75 p.s.i. The lap-joint specimens withstood shock of the 3000 lb. hammer with 3 in. table travel and hammer drops of 1, 2, 3, 6, 9, 12 and 15 in. totaling 7 blows without leakage.

The eighth blow caused the joint to fail in shear and the pipe to break near one support. This performance of the plastic was considered satisfactory, especially in view of the fact that half the wall thickness of the tube was machined off to form a lap joint. The plastic-to-bronze joint withstood 6 blows but the sixth caused refracture of a repaired section in one tube. The flanged, copper-nickel tubing did not leak throughout the complete test of 11 blows, the last four of which were hammer drops of 21 in. The metal tubing deformed on the fourth blow and became reduced in diameter at the hanger. The ends of the metal tubes bent upward to an angle of 5 degrees outside the supports.

LARGE-SCALE FIRE TESTS

The Industrial Test Laboratory at the Philadelphia Naval Shipyard evaluated the performance of reinforced plastic, aluminum and copper-nickel alloy piping when exposed to large-scale fires under conditions simulating those which might occur in service. Valuable assistance was given by personnel of the Fire Fighters' School, whose facilities were used for the tests. The plastic piping was glass-reinforced selectron 5016 resin polyester. It was coated externally with "Albi-R" fire-retardant paint which swells to produce a "burned marsh-

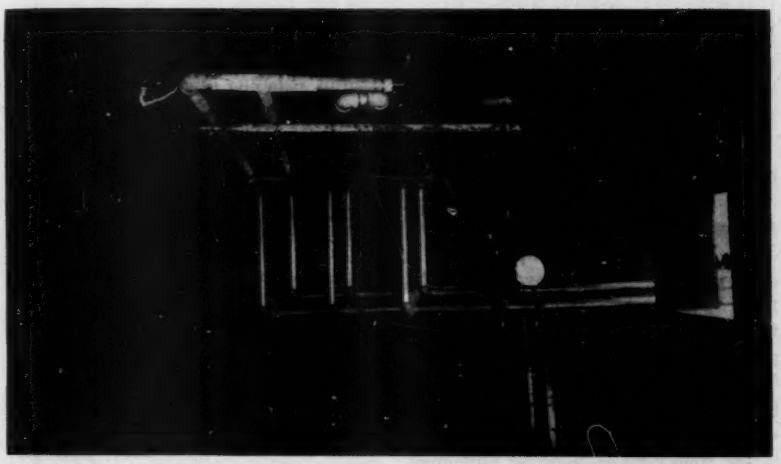

FIG. 4—Plastic, Aluminum and Copper—Nickel Piping Set up for Large-Scale Fire Tests.

mallow" effect in a fire. The aluminum alloy was 61-S. Piping assemblies of each material were erected side by side in an oil-flooded structure simulating the hangar deck of an aircraft carrier (Figure 4). Each system consisted of two 10 ft. lengths of tubing. a short nipple, and a few fittings. Piping was supported by two hangers so that it was 6½ ft. above the level of the oil. All piping was 2 in. nominal size. No thermal insulation was applied.

FIG. 5—Large-Scale Fire Test of Plastic Piping.

Following erection of the plastic piping on the site, the compartment was flooded with approximately 10 in. of water and 3 in. of oil. Three tests were conducted (Figure 5).

In test No. 1, water was flowing through the piping at a velocity of about 3 f.p.s. at a pressure of 150 p.s.i. The fire was permitted to burn freely for 5 min. An additional minute and 40 sec. were required to extinguish the flames completely. It is necessary that fires be of limited duration to prevent permanent damage to the test structure. The maximum temperature recorded at the piping was 1900°F. There was no visible evidence of warping or damage to the copper-nickel alloy or aluminum systems. A close visual examination showed the damage of the plastic piping had been limited by the "Albi-R" fire-retardant coating. Only a few scattered, scorched areas penetrated the surface of the plastic. A hydrostatic test showed that there were no leaks except those which had been noted prior to the start of the run.

In test No. 2, which followed test No. 1 within 15 min., a static head of water was applied to the system at 150 p.s.i. Duration of the fire was 2½ min. with an additional 1½ min. required to extinguish it. The maximum temperature of 2020°F. recorded at the piping was the highest measured in all the tests. The fire was extinguished when the aluminum tubing ruptured by explosion (Figure 6). A hydrostatic test showed that the copper-nickel alloy did not leak nor was it warped. The plastic piping did not leak but the charred areas of plastic were larger and more numerous.

Test No. 3 followed within 15 min. of test No. 2. The piping was drained of water and all valves were open. The duration of the fire was 3 min. and it took 30 sec. to put it out. The maximum recorded temperature was 1850°F. After the oil fire had been extinguished the plastic continued to burn slowly for 7 min. This was the only observed instance of burning piping. At many points the resin had completely burned away, leaving only the glass cloth. There was considerable porosity along the

FIG. 6—Piping After Fire Showing Ruptured Aluminum.

length of the tubing (Figure 7), but no leakage in the vicinity of the tee. Sagging of the aluminum piping became more pronounced and it was melted through at one point. The copper-nickel alloy piping was slightly warped; however, when water was pumped through the system subjecting it to thermal shock, no leakage occurred.

Conclusions of the large-scale fire tests were as follows:

(a) Glass-reinforced polyester plastic, aluminum alloy and copper-nickel alloy piping systems are resistant to destruction by fire while water is flowing through the system.

(b) Plastic piping burns and becomes porous, while aluminum piping warps, melts and becomes unusable under heat conditions which do not seriously affect copper-nickel piping.

(c) Copper-nickel piping does not leak and is usable following large-scale fire tests.

It is planned that further large-scale fire tests will be made in order to determine whether there is a significant difference between the fire resistance of glass-reinforced tubing made with polyester or with melamine and phenolic resins.

EFFECT OF WEATHER ON BONDING OF JOINTS

The fire tests were run in March 1951. This erection of plastic piping with bonded threadless joints was the first outdoor installation. Unforeseen minor difficulties were encountered during the use of adhesive resin in cold rainy weather. The resin was Marco MR-28C catalyzed to gel in 30 min. at room temperature. Unfortunately, the ambient temperature was a humid 46°F. when resin was injected by the grease-gun technique. It had not gelled after 21 hours, so smoke pots were placed in the open compartment to raise the temperature sufficiently to effect a cure. After 4 hours at approximately 80 to 110°F. the resin hardened. There was some leakage at two joints upon application of 150 p.s.i. water pressure. This experience is of obvious significance in considering installation of plastic piping in vessels under construction at shipyards where cold, humid weather may prevail.

FIG. 7—Piping After Final Fire Showing Porous Plastic.

SHIPBOARD TRIAL

In order to expedite development of plastic piping for conservation of critical metals, a trial installation on a naval vessel was planned. Representatives of seven firms known to be interested in naval use of plastic piping were invited to a naval shipyard to inspect a destroyer escort. The purpose was to familiarize potential suppliers of plastic piping with the problems peculiar to shipboard use. Visitors were duly impressed by the maze of equipment and piping with branch connections, bends, valves and fittings crowded into the machinery space of a naval vessel. Only two companies at that time recommended that their material be installed on the ship. One firm offered glass-reinforced, thermosetting plastic. The other was a producer of a complete line of thermo plastic pipe and fittings. These firms were the U.S. Plywood Corp. and the Carlon Products Co., respectively. Reinforced plastic was the material desired because of its high strength and maximum heat resistance.

In May 1951, Norfolk Naval Shipyard accomplished the plastic piping installation with the invaluable assistance of the U.S. Naval Engineering Experiment Station. Because the work had to be completed prior to the ship's scheduled departure, the installation was limited to four locations considered most suitable for evaluating performance of the plastic. Piping totaled about 85 feet as follows:

(a) 40 feet of tubing with 5 couplings, 5 ells and 2 tees in the flushing main (Figure 8), located forward in the crew's mess and berthing area under a 5 inch gun.

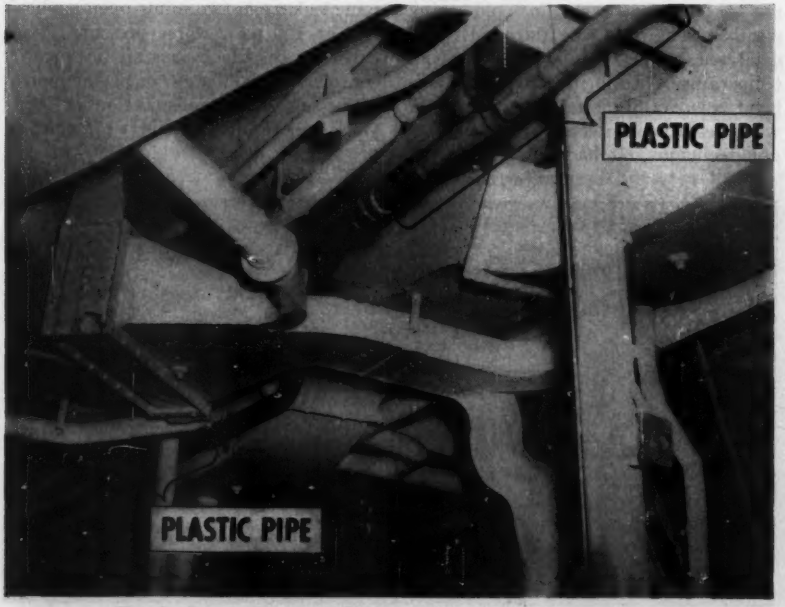

FIG. 8—Plastic Piping in Flushing Main of a Destroyer Escort.

(b) 20 feet of tubing with 2 couplings and 3 ells in a branch from the firemain to a fireplug and located in a fireroom where the plastic runs over the top of a boiler.

(c) 13 feet of tubing with 2 couplings and 2 ells leading to a fireplug and located on the outside of the deck house.

(d) 12 feet of tubing with 2 couplings in the firemain located aft in the crew's berthing area.

This installation subjected the piping to the following test conditions:

(a) Mechanical shock and vibration (under 5 inch gun).

(b) High ambient temperature (above boiler).

(c) Constant service (flushing main.

(d) Pressures of 90 p.s.i. in the firemain and 35 p.s.i. in the flushing main.

(e) Weathering effects (on deck).

(f) Sweating of piping, half of which was insulated at each location inside the vessel.

(g) Bulkhead and deck connections.

The plastic piping parallels the existing ferrous system and is arranged so that the metallic piping could be cut into use should the plastic fail completely.

Tubing was furnished in 10 feet lengths with 2⅜ inch O.D. and 2 inch I.D. It was made with the outside diameter ground to a close tolerance. This permitted cutting a tube to any needed length during erection and assembly with plastic sleeves and fittings by the bonding method developed by the Station. Tubing and couplings were made with polyester resin. Selectron 5007 which United States Plywood Corporation had readily available. Tees and 90° ells were made with Laminac 4128 which cures at room temperature and handles easily in the method used for making fittings. All components were made with glass cloth.

Metal-to-plastic adapters were made of 2 inch galvanized wrought iron pipe. Deck and bulkhead sleeve fittings were made of wrought iron pipe welded to the bulkhead. They had grease fittings at either end for injection of bonding resin to seal the plastic tubing passing through the sleeve. All joints were the threadless bonded sleeve type. The female part of the joint was machined internally with 4 grooves to the inch—0.010 inch deep x 0.062 inch wide. Sockets were 1½ inch deep except the ells which had 1¼ inch sockets. Pipe hangers were spaced about 5 feet apart with rubber impregnated cloth placed between the clamp and tubing.

Self-curing polyester resin, Marco MR-28C, was used to bond all joints. Data were available for proportioning the resin, catalyst and accelerator to obtain proper gel for any temperature likely to prevail. The weather was warm and resin was mixed by batch to gel in 30 minutes.

The first sections of plastic tubing were installed in the firemain. The piping was erected in place and the resin injected through the lubrication fittings located either on top or the sides of the joints. The next day the system was tested at 60 p.s.i. Leakage occurred in 3 out of 14 joints. The piping was drained and the leaks repaired by wrapping with resin impregnated glass tape.

It appeared that bonding by injection of resin into dry joints was unsatisfactory. Unavoidable misalignment of piping caused tight spots with insufficient clearance for even flow of the resin. Leaks may have been due also to run-out of the resin during cure. To overcome these difficulties, the remainder of the joints were made by brushing the mating surfaces with resin during

assembly. Resin was also injected in the regular manner while the joints were still wet. In a few cases where it was not possible to paint the joints, extra grease fittings were added to distribute the resin. This method was satisfactory and no leakage occurred from any of the 45 joints. However, one plastic coupling leaked and was repaired.

Pipefitters who had never before seen plastic piping commented favorably on its light-weight, cleanliness and ease of installation. Inability to bend the tubing was not considered a serious disadvantage providing sufficient standard pipe fittings were available.

After 8 months of service the destroyer escort Engineering Officer reported as follows:

"1. Resistance to shock and vibration is considered to be good. Severe stress and vibration during a storm has produced no visible damage to the plastic piping, although several metallic lines gave way.

2. The plastic piping has been subjected to temperatures as high as 125°F. with no apparent damage.

3. No deficiencies have been noted in weather deck piping.

4. The plastic piping does sweat, but the degree of condensation is estimated to be approximately 50 percent of that found on metallic piping systems.

5. Method of support appears to be satisfactory.

6. Joints and bulkhead connections appear to be satisfactory.

7. The use of plastic piping appears to be completely satisfactory, up to the present time."

WORK CURRENTLY UNDERWAY

In view of the extremely critical status of copper-nickel alloy and the favorable experience with plastic piping aboard ship, glass reinforced polyester tubing and pipe couplings are being installed in a minesweeper. Because plastic fittings are not developed to the extent that tubing is, cast-brass, solder-joint pipe fittings in accordance with American Standard ASA B16.18-1950 are being used. These fittings have been selected because of their deep sockets which provide sufficient area for bonding the metal-to-plastic joints. The brass fittings were designed for use with copper water tubing which does not have IPS dimensions. The plastic tubing is being made with outside diameters based on copper water tube. Tubing tolerances are such that a tube may be cut to any length and inserted into a fitting without further preparation of the end. An improved technique for making bonded joints is being developed. Ethoxyline and polyester adhesives are being tested. Methods of applying heat to joints, such as by hot air or steam, are being studied.

The use of plastic tubing made to copper water tube dimensions is an interim measure. Development of reinforced plastic pipe fittings is being based on IPS dimensions. It is not desired to develop special deep-socket metal fittings. Work on plastic fittings is continuing but this phase lags far behind tubing. A purchase specification for reinforced-plastic tubing is being prepared. Commercial interest in reinforced-plastic pipe fittings has been limited until recently.

Tubing for the minesweeper installation is being furnished in the range of sizes from ½-inch through 5 inches. Its

use is planned for sea water, hot and cold fresh water, and low pressure air service. The maximum temperature is expected to be 180° F. Tubing is nominally rated at 150 psi working pressure with 450 psi hydrostatic test by the manufacturer. This plastic tubing weighs one-third as much as copper-nickel alloy tubing. Glass-cloth-reinforced plastic tubing prices are higher than copper-nickel alloy at present. Reinforced-plastic tubing is expected to become competitive with steel pipe as improved methods of manufacture and increased usage come into being in the near future.

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OBSERVATIONS ON EXPERIENCE WITH WELDED SHIPS

ACKNOWLEDGMENT

This paper discusses the experience acquired with welded construction of merchant ships in the shipyards of the United States prior to and during the war construction program. It was written by DAVID P. BROWN, Senior Vice-President and Technical Manager of the American Bureau of Shipping. Prepared for the plenary session of The International Institute of Welding in Gothenburg and for the Fall meeting of The American Welding Society in Philadelphia during the week of 20 October 1952, it was published in the September 1952 issue of "The Welding Journal."

From reports and statements which have been made from time to time as a result of the very spectacular and consequently greatly publicized failures of some welded seagoing ships, one is very liable to get the impression that welding in the shipbuilding field in the United States was adopted strictly as a wartime necessity. The emphasis which has been placed upon the benefits of welding resulting from the ability to establish entirely new shipbuilding plants, to recruit the tremendously large numbers of hitherto untrained workers to man these plants and to produce ships quickly on a mass production basis as was so necessary for the successful prosecution of the recent World War may have led many to believe that these were the predominant factors leading to the adoption of welding as a medium for the construction of ships' hulls. It is true that these conditions undoubtedly accelerated the transition from riveted to welded construction and that they have had a decided influence on the almost complete transition which has taken place in peacetime construction in the United States shipyards and the experience acquired has no doubt had some influence on the corresponding trend in the shipbuilding plants in many other parts of the world.

WELDING IN THE PRE-WAR PERIOD

For many years prior to the war emergency period, ship designers had recognized the many attractive possibilities of the application of this new medium for joining the many structural parts comprising a ship's hull. It has always been the object in all sound engineering designs to strive for the most economical structure, from the standpoint both of first cost and maintenance, which will satisfactorily perform the services for which it is in-

tended. In the fields of stationary structures such as storage tanks, bridges, buildings, etc., the problem is generally primarily one of obtaining a balance between first cost and maintenance, economy of material and resulting final weight of structure being of secondary importance only in so far as they affect these two factors. In a ship's structure, however, where the container and its contents are expected to be in transit for a good part of the useful life, every pound of redundant material represents a potential reduction in the earning capacity of the ship spread over its entire service career. Practically all seagoing commercial ships of large size are limited in the total weight of the container and contents by International load line Regulations which place a limit on the depth to which they can be loaded and in many cases further limitations may be imposed as a result of available depths of water at the terminals or in channels or canals. Even in those cases where draft limitations may not be the controlling factor, such as in the case of a light ship proceeding in ballast or when carrying a light cargo using all available cubic, redundant weight in the hull structure is reflected by added fuel costs or reduced speed in transit. A great many owners and operators also recognized the possibilities offered by welding in the elimination of some of the nuisance repairs with which they had been faced with riveted ships. It is not an uncommon experience to find, on periodic examination of these ships, large numbers of rivets which require renewing on account of an advanced degree of wastage of the rivet points or owing to their having become loosened as a result of slamming in heavy seas or working in highly stressed areas.

It is no wonder, therefore, that even before the war emergency conditions added impetus to the use of welding in shipbuilding, great strides had been made in its adoption. In 1917 when the shipyards of the United States were confronted with the necessity of producing ships in large quantities, the authorities having charge of the construction program appointed a committee to consider the construction of welded ships in view of the, then, general belief that the chief obstacle to the construction of large quantities of steel ships was the lack of trained riveters. Plans were prepared for a standard type of 2-deck cargo ship, 401 ft. long, 54 ft. beam and 32 ft. 10 in. deep. It was proposed to construct the ship in transverse sections each 6 ft. long and comprising a double bottom section plated transversely, a side section plated vertically and deck sections plated transversely. The keel, center girder and rider plate, the bilge strakes, the sheer strake and deck stringer plates were plated longitudinally in 30-ft. lengths with the idea of reducing the number of joints in these important members. A contract was given to one of the shipyards for the construction of a full-size experimental mid-section subassembly and the work was well under way at the time of the Armistice in 1918. About two weeks before the Armistice, authorization was given for the construction of a complete all-welded vessel but shortly after the Armistic both of these projects were canceled. This was, in my opinion, very unfortunate since the experience which might have been gained in the construction of a large all-welded ship, especially if combined with a satisfactory service record, would have undoubtedly accelerated the application of arc welding to ships under peacetime conditions and in a more orderly manner than was possible during the recent war years.

The deliberations of this Committee had one important result in that some of its prominent members, realizing the need for a Technical Society devoted exclusively to the study of welding problems, took steps which led to the formation in 1919 of the American

Welding Society, which has since done so much to promote and advance the science and art of welding in American industry and which, through its affiliations with other similar groups throughout the world, has made available a world-wide exchange of information relating to research work and new developments in the field of welding.

During this era the use of electric arc welding in shipbuilding was generally confined to repair work, to the rectification of defects and in the case of new construction to those parts of the ship which were considered to be structurally unimportant; such items being listed by the Classification Societies as a guide for their surveyors. Failures of welds due to improper equipment or unskilled workers were not uncommon and these served to prejudice many shipbuilders with a background of riveting against the use of welding and served to delay its more general adoption. Fortunately, however, there were a number of individuals—not only those primarily interested in the promotion of welding but also among shipbuilders and shipowners—who, recognizing the economic advantages of this new medium, were not content with this state of affairs, and some of the leading shipyards in the United States inaugurated pioneer experimental work in their own plants and instituted schools for the training of welding operators with the result that an ever increasing amount of welding was done in succeeding merchant ships.

In 1921 there was built in England what is purported to be the pioneer all-welded seagoing merchant vessel, named the *Fullagar* and later named the *Shean*. She was a very small vessel being only 150 ft. long by 23 ft. 9 in. beam by 11 ft. 6 in. deep. She operated for a number of years in the coasting trade during which she suffered the usual mishaps including a severe grounding and later she crossed the Atlantic and was placed in coasting service in British Columbia. This vessel performed a very useful service until the summer of 1937 when she was sunk following a collision.

In the field of small vessels, during the middle 1920's, the development of welding as a substitute for riveting took place rapidly in the United States, particularly in the case of small tankers operating in river and harbor service, where superior oil tightness and freedom from the usual rivet troubles, experienced as a result of frequent bumping or grounding, made this new medium attractive to the owners. The majority of such vessels were towed barges of simple rectangular cross section with rake ends in which nearly all of the work was straight work and in which the assembly and erection problems are simple as compared with a vessel of ship form.

In 1927 the American Bureau of Shipping, with which Society the great majority of these vessels were being classed, decided that it was prepared to express a degree of confidence in this type of construction as is necessary to obtain the highest classification so that the Rules of that year provided for the classification of all-welded ships with a notation "Metal Arc Welded" after the usual classification symbols, it being considered that any reference to the classification being experimental was quite unwarranted.

Following these meager beginnings, the use of welding was continuously extended to somewhat larger vessels including the coastwise types of self-propelled tankers of ship-shape form with the result that, by 1940, riveted construction of all types of floating equipment of under 300-ft. length had practically disappeared, all of these smaller vessels being completely welded. Experience gained in the construction and operation of small all-welded coastwise tankers gave the builders and the owners

of several vessels of this type confidence to go ahead with the welded construction of a large oceangoing tanker in 1937. This vessel, the *J. W. Van Dyke,* was 521 ft. long by 70 ft. beam by 40 ft. deep, had a deadweight capacity of 18,105 tons and a gross tonnage of 11,650. The construction of this vessel constitutes a milestone in the development of welded construction for ships' hulls since it represents the first application of welding to a hull structure which required the use of materials of thicknesses approaching those as are now commonly required in the modern large welded merchant vessels, and many of the details of the structure compare very closely with those which are still being followed. In addition, it was in the construction of this vessel that automatic welding on a large scale was first used in shipyard work. In this first vessel of its type the ends beyond the cargo tank spaces were generally of riveted construction, but in the construction of succeeding vessels immediately following the *Van Dyke* the riveting at the ends was replaced by welding so that this particular vessel might be said to be the prototype of our modern large all-welded tankers.

The establishment in 1937 of a Maritime Commission in the United States with authority to inaugurate a long-range shipbuilding program at the rate of 50 ships per year over a 10-yr. period gave added impetus to the use of welding in ship construction. A number of the established shipyards participating in this program had available a nucleus of personnel trained and experienced in welding, resulting from continuous experimentation and the increasing use of welding in their plants, and the Commission very properly decided to allow the various builders to rivet or weld as they saw fit. These contracts were spread throughout all of the then existing shipyards in the country and they generally called for only four to six ships of one type in any one particular yard. Under the option permitted by the Commission the different yards elected to use welding in widely varying degrees from the practically all-riveted ship to the all-welded ship. With the outbreak of hostilities in Europe, it was recognized that the demands on the merchant tonnage of the world would be tremendously increased and authority was granted to the Maritime Commission to accelerate the construction program with the result that a large number of additional contracts were placed with the yards who were participating in the original program. The placing of firm orders for additional ships and the anticipation of still further contracts, resulted in a number of yards, who had elected to use a large amount of riveting on the original ships, replanning their designs for the new orders to take advantage of the large subassembly system of construction in association with more and more welding.

WELDING IN THE WAR-EMERGENCY PERIOD

As a result of these activities by the time the shipbuilding industry was confronted with the necessity of greatly expanding the building capacities to meet wartime emergency demands, welding had become almost universally adopted and it was no wonder that when the British Government decided to supplement the already overtaxed shipbuilding facilities in the United Kingdom and Canada by arranging to have 60 vessels built in the United States, the two new plants established to build these vessels were laid out and equipped for building all-welded ships. These two plants were the forerunners of a number of such plants which were built in the years immediately following and in which there were produced during the war years the miraculously

large numbers of Liberty Ships, Victory Ships and T2 Tankers.

In one way it is perhaps unfortunate that the shipbuilding industry should have been required to plunge into the wholesale adoption of welding under wartime emergency conditions before having acquired any real length of service experience with large all-welded ships built under more normal conditions, since some such experience might possibly have pointed at some of the pitfalls into which we innocently fell. On the other hand, the building of so many ships, identical in design, has afforded those of us who have access to the service records of these ships, an opportunity of analyzing the different structural difficulties and of avoiding false conclusions which might have been arrived at from only one set of circumstances. Never before in history have there been so many vessels of one type operating under the varying conditions all over the world and it is by a continued study of reports of damages that we have been able to isolate certain factors contributing to these damages to the end that these can be eliminated or circumvented.

For instance, were we to have only 20 ships identical in every respect and a structural failure, either serious or inconsequential should develop in only one of these ships, it is not believed that, unless there should be a glaring defect in design, one would consider it necessary to adopt corrective measures for application to the other 19. However, when we are observing records covering over 400 identical vessels such as in the cases of the Victory ships, nearly 500 in the cases of the T2 tankers and of over 2500 as in the case of the Liberty ships any type of structural trouble, if there is some inherent fault involved, has a far greater chance of being repeated several or even a large number of times and through such repetition the finger is oftentimes pointed at the fault, and corrective measures which can be applied to the remaining ships or at least to subsequent ships are in many cases quite definitely indicated.

Even if all-welded construction had had a long background of experience prior to the commencement of the war emergency program, it would not be unreasonable to have expected some difficulties with the ships built under this program. The magnitude of the program was considerably beyond the normal capacities of the shipbuilding industry in the United States and it was necessary to construct entirely new yards, to recruit and train labor from all walks of life including many workers who had had no previous association with the hard manual labor involved in shipyard work. The management and supervisory personnel were for the most part drawn from the established shipyards who were already working to capacity and as a result it was necessary to spread very thinly the actual "know-how" of shipbuilding. It is, therefore, not surprising that there would have occurred some serious failures in these warbuilt ships, whether they had been riveted or welded, and the relatively small number of serious failures among the more than 4000 predominantly welded ships is less to be wondered at than the entirely satisfactory service provided by the remaining thousands. Failures of varying degree of severity have occurred in all types of ships ever since ships have been built and these failures have been an ever present challenge to the designers. While in this paper, reference may often be made to failures in welded ships, it is not intended to create the impression that there is any distrust of the use of welding as a medium for the construction of ships' hulls, but it is only through a proper recognition and study of the failures that designers and builders can provide the necessary safeguards against their repetition.

EARLY CASUALTIES

The first Liberty ships produced in the newly created emergency shipyards were placed in service near the end of 1941. They were being rapidly produced from that time on so that by the middle of January 1943 there were in service approximately 500 of this type of vessel. Up until that time there had been accumulated reports covering 10 fractures in the hull structure which were considered to have occurred in such locations and to such extent as to cause concern as to the safety of the vessel, most of these having occurred during the more severe weather conditons of the late fall of 1942 and the start of the 1942-43 winter season. These fractures were being made the subject of very serious study by the staff of the American Bureau of Shipping, with whom these vessels were classed, when the whole problem of welded ship failures was highlighted by the spectacular breaking in two on Jan. 16, 1943 of the T2 tanker *Schenectady* while lying at the builder's outfitting dock shortly after having completed her trials. The nature and extent of the break of this vessel was certainly without precedent in shipbuilding history and it occurred without apparent provocation. The vessel broke across the deck just abaft the after end of the bridge about amidships, the fracture extending down both sides and around the bilges to the bottom shell plating which remained intact. All deck, side and bottom longitudinal frames fractured as did also the plating of the corrugated longitudinal bulkheads and the heavy deep girders on the centerline at the deck and bottom, thus constituting a complete failure except for the flat portion of the bottom shell plating. In no case did the fractures occur in the transverse welds.

In most cases of fractures reported prior to this incident the finger of suspicion had been pointed at specific design details, such as square hatch corners or square cutouts in plate edges at highly stressed locations, which, coupled with inferior workmanship, had quite apparently been the cause of the fracture and corrective measures were beginning to be quite clearly indicated. However, in the case of the *Schenectady* these conditions were not so readily apparent and there were implications that there was something rather more fundamental in the susceptibility to fracture of the large monolithic structure created by welding. In realization of the seriousness of these implications the American Bureau immediately appointed a committee of experts in welding and shipbuilding to investigate the causes of the *Schenectady's* failure. In its investigations this committee found no basis for believing that any of the alleged contributing factors, such as shock resulting from the breaking of an anchor chain during the trial trip, the silting of the river under the mid section of the vessel to form a bar, or a shock caused by an earth tremor, could have had any bearing in the case. The report of this committee presented a diagnosis based upon theories of locked-in stresses which have proved to be of such controversial nature in the years since this fracture and on which there is still considerable disagreement. The report stated that the principal cause of the failure was "an accumulation of an abnormal amount of internal stress locked into the structure by the process used in construction together with an acute concentration of stress caused by defective welding at the starboard gunwale in way of the abrupt ending of the bridge fashion plate, augmented by the hogging stress due to the ballasted condition." Among the contributing causes mentioned were the lack of trained experienced supervisors, welders and shipfitters resulting in departures from good welding procedures

and the excessive forcing of poorly fitted subassembles with consequent excessive welding.

On this committee was included a prominent Metallurgist and Consulting Materials Engineer from one of the large colleges and under his direction there were made complete investigations of the steel involved in the fracture. It is significant to note that through his contribution to the investigation there was first brought into prominence the question as to whether or not specifications which had always been considered satisfactory to provide steel of adequate quality for riveted shipbuilding purposes were sufficiently comprehensive to insure materials suitable for large welded structures. The investigation disclosed that there had occurred a drop in air temperature of from 38° F. at 2:30 P.M. to 23° F. at 11:00 P.M., the time of the fracture. It was believed that while this drop in air temperature of 15° F. over a period of 8½ hours was not extreme as to suddenness, it did introduce a factor in respect to the increased brittleness of steel at low temperatures, a property over which the then existing hull steel specifications had no control.

Following the *Schenectady* incident there occurred a number of equally disturbing fractures in welded ships. A large Great Lakes type bulk freighter, while nearing completion at the builder's dock, suddenly fractured across the deck and part way down the sides; a Liberty ship suddenly suffered a fracture in the deck and part way down one side while being loaded at a pier; and in March 1943 another T2 tanker, a sister ship to the *Schenectady*, but built in a different yard, suddenly split in two at the entrance to New York harbor under sea conditions which apparently were very moderate.

Throughout the winter of 1942-43 additional reports were being received covering fractures occurring in the increasingly large numbers of welded ships in service but these were by no means as numerous or serious as many were led to believe from the glaring press headlines and numerous investigations. The secrecy of wartime operations undoubtedly added to the popular belief that there possibly may have been many more failures than were actually released for publication. Nevertheless, the American Bureau of Shipping felt that even only one unexplainable fracture was a matter of grave concern and their staff pursued diligently the study and classification of the reports received in an effort to modify details and correct practices, where practicable steps were indicated.

INVESTIGATIONS OF CASUALTIES

It was apparent that the introduction of welding of the large ships' hull structures had brought forth the need for a more scientific understanding of the problems involved as, for instance, why should a minor crack once started in a defective weld or at a structural discontinuity continue in some cases to propagate with lightning speed until it resulted in the complete severance of the hull girder whereas in other cases under no less severe conditions, the crack might extend for only a few inches or feet. The United States Coast Guard in which agency is vested governmental responsibility for the safety of merchant vessels and whose functions during the war years had been placed under the Navy Department, requested the Secretary of the Navy to establish a committee with authority to conduct such investigations into the designs and construction methods of welded merchant vessels as they saw fit and to initiate such research projects as their investigations might indicate as being desirable. Acting upon this request the Secretary of the Navy in April 1943

appointed the "Board of Investigation to Inquire into the Design and Methods of Construction of Welded Steel Merchant Vessels." This Board was comprised of representatives from the U.S. Coast Guard, the U.S. Navy Department, the American Bureau of Shipping and the U.S. Maritime Commission which was at that time the owner of all seagoing merchant vessels being built in the shipyards of the United States. Under the auspices of this Board there was undertaken an extensive program of investigation of all of the factors relating to the ship failure problem. Technical and statistical analyses of all casualties were carried on, a review was made of the design of each type of vessel involved, loading and ballasting conditions were checked and analyzed, sea and weather conditions on the various routes were examined and many specific investigations and research projects were initiated. In addition, close liaison was maintained with the shipyards, and with other organizations who were investigating related problems both in the United States and in Great Britain.

This Board continued these activities under its direction until July 1946 when it made a final report to the Secretary of the Navy. This report covers all phases of the many investigations carried out and presents a number of conclusions. It has now come to be regarded as a classic in the annals of welded shipbuilding and serves as a very valuable reference to many designers of welded structures in fields other than shipbuilding.

In appreciation of the tremendous volume of statistical data which would require to be assembled and analyzed, the working group which was established under this Board and which was known as the Sub-Board first decided that it would be necessary to establish certain definitions for the classification of the failures and since these have become more or less common parlance in the United States in any discussions of ship failures they are repeated in somewhat different form but in the form in which they will be used in the succeeding parts of this paper.

Casualty: A casualty consists of one or more structural fractures occurring on the same occasion on a vessel which is afloat. Unless otherwise stated, the casualty occurred under normal operating conditions and does not include fractures resulting from collisions, groundings, gun fire, torpedoes or mines.

Group I Casualty: A Group I casualty is one which includes one or more fractures in the shell, strength deck or other important parts of the structure contributing to the over-all longitudinal strength of the main hull girder and which has extended to such a degree that it has weakened the structure so that the vessel is lost or is in a dangerous condition.

Group II Casualty: A Group II casualty is one which does not include any fractures comprising a Group I casualty but which includes one or more fractures in the shell, strength deck or other important parts contributing to the main longitudinal strength, or in appendages thereto such as in bulwarks or bilge keels. In general, these fractures are less than 10 ft. in length but they are in such locations where experience has shown they might readily have propagated into the type of fracture of a Group I casualty.

Ship-year: A ship-year is a unit for measuring the length of service records of any one ship or type of ship. It is equal to the service of one ship for one year. For example, 10 ship-years can equal 10 ships operating for 1 year, 2 ships operating for 5 years or 1 ship operating for 10 years. In citing ship-years of service records in the following parts of this paper there is included for each ship of any group, only the length

of time the ship was actually active and subject to the usual surveys as required for the maintenance of classification with the American Bureau of Shipping and for which our report records are complete. For ships which have been laid up, the time during lay-up has not been counted as contributing to the ship-years of service records and for ships which have been withdrawn from class either on account of having been assigned to Military Authorities or on account of being transferred to some other classification society, their length of service subsequent to the withdrawal from class has not been included.

The Sub-Board, in accordance with American Bureau practice, included in their studies a third group of casualties comprising fractures which do not fall into the Group I or II classifications, such as those in internal structure at stanchion connections, lower decks, peak structures, etc., and in particular those in the bulkheads or web frames of tankers. Much has been written concerning these types of failures and changes in details have been pretty clearly indicated to accomplish their elimination. It is not the intention in this paper to discuss such failures but to confine the remarks to the Group I and II types and to discuss the lessons learned from them, and what measures can be and are being taken to guard against their occurrence.

For the many miscellaneous types of ships for which contracts had been awarded under the original long-range program of the Maritime Commission and which had been extended under the accelerated program and in the construction of which permission had been granted to the individual builders to adopt welding in such a degree as they saw fit, there were many different combinations of riveting and welding. The basic construction plans for the Liberty ships, which were originally intended to be required to be followed by all of the yards building this type of ship, on account of a centralized material procurement plan, called for all parts of the structure to be welded except for the connections between the side frames and the shell plating which were to be riveted. This arrangement was generally followed in most yards but some of the builders elected from the start to weld the frames and in some of the yards changes were made at some stage of the program to eliminate the rivets and to substitute welding. Also, in the Bethlehem-Fairfield yard, where a special procurement plan was contemplated, the Commission did at the request of the builders permit the use of riveted shell seams in association with welded frames.

It is most difficult to set up any hard and fast definitions for the nature of construction to be used for statistical purposes in the comparison of service records of different types of ships. An all-welded ship or an all-riveted ship is easy of definition but one cannot clearly establish at just what stage a structure should be considered as a welded structure with some riveting or a riveted structure with some welding. However, for the purposes of this paper, it has been assumed that where all the seams and butts of the shell, inner bottom, and strength decks and all connections between these parts are welded, the ship is to be considered as being all-welded, irrespective of the method of attaching the frames. There are some who feel that the riveting of side frames may have an effect on certain conditions existing in the over-all structure, to the extent of influencing the performance in service. In the statistical studies cited in this paper, no attempt was made to make a definite separation between the ships with riveted or with welded frames, all other arrangements being alike, nevertheless some sampling of the figures failed to show any definite effects.

CONDITIONS OF OPERATION

In the investigations of welded ship problems it has generally been accepted that these could be roughly separated into four broad phases; i.e., conditions of operation, design, workmanship and materials. With regard to the first of these phases there is no doubt but that the conditions of wartime operations imposed unusual hardships on the vessels, requiring, as they did, trading in convoys, in many cases over severe sea routes which would be only infrequently used in normal times. The demands for speedy turn-arounds and the last minute assignments of cargoes which would not permit of any planning of loadings likewise contributed materially to some of the failures experienced. In some respects it may have been unfortunate that very little service experience had been acquired with welded ships up until they were required to be constructed in such quantities and operated under the exigencies of wartime service, since it is undoubtedly true that comparisons between the records of these ships and the records of prewar riveted ships operating under peacetime conditions may be masked by the conditions of operations. None but the most biased against the large-scale use of welding in place of riveting can help but recognize that even had it been possible to produce such large quantities of riveted ships, constructed of materials and in accordance with designs which had been tried and proved over many years of steel shipbuilding experience, there would surely have been an increased number of casualties resulting from the conditions under which the ships were required to be built and the more severe conditions under which they of necessity had to be operated. On the other hand, there are benefits resulting from having had to plunge these ships into such arduous tests in that the larger number of casualties resulting therefrom have afforded the opportunity of more comprehensive study to the end of pointing the way to improvements to insure greater margins against the extraordinarily severe conditions which might require to be met in peacetime even if only very infrequently. One cannot completely ignore the casualties which occurred where, by no stretch of the imagination, could extra severe conditions of wartime operation be said to be a contributing factor, such as those that occurred at the builders' docks, while in port, or since the war and in particular during the past winter, during which even though sea conditions were unusually severe, they could hardly be said to be a "wartime" condition.

DESIGN

It was in the field of design that opportunity was had during the construction program to take the most positive steps toward improving the performance of these welded ships. When casualties to Liberty ships were first receiving great publicity it was believed by many that sacrifices had been made in the structural strength of the ships' hulls in the interests of conserving steel and with the idea that the ships were to be considered as wartime expendables. Stories were rife as to the light construction of these ships, in some cases referring to them as "tin-cans." These beliefs and stories were entirely without foundation.

When the Maritime Commission was confronted with the necessity of establishing new shipyards and constructing large quantities of ships under the emergency program there was a great division of opinion as to the type of ship to be built. There had been developed in Great Britain a popular type of general utility vessel and contracts were

under way for the building of a large number of vessels of this type, primarily riveted, in the shipyards in Canada. When arrangements were made to have 60 vessels of substantialiy the same general characteristics built in the United States, it was decided that the two new yards which were to be created for this purpose would be planned for the construction of primarily welded ships and the plans which were developed for this program generally followed those for the riveted prototypes, merely being changed to substitute welding for riveting. These ships (later designated as the "Ocean" type) were designed to the then existing standards of Lloyd's Register for a draft of 18 in. in excess of that which could be obtained as a shelter deck vessel. The authorities in the United States finally agreed that vessels of substantially the same general characteristics should be adopted for the large-scale production of emergency ships of the so-called "workhorse" type (later designated "Liberty" ships). It was originally intended to keep the two types of vessels as nearly alike as possible so as to facilitate a central procurement plan particularly for forgings, castings, rudders, etc., so that these could be ordered out from subcontractors' plants as the need arose in the different shipyards participating in these two programs. However, it was decided that in order to meet production facilities in the United States and to make the vessels more suitable for United States operation, the boilers of the Liberty ships were to be changed from the scotch type to the watertube type and they were to be oil fired instead of coal fired. These changes entailed a considerable rearrangement of the ships so that opportunity was taken to redesign the hull. The open shelter deck features were eliminated and the vessels were redesigned on the full scantling basis with the scantlings all strictly in accordance with the Rules of the American Bureau of Shipping, with which these vessels were to be classed, at the deeper draft permitted.

In the case of the T2 tankers concerning which there were also a number of weird rumors, the structural scantlings for these vessels were all strictly in accordance with the Rules of the American Bureau of Shipping. The structural design was patterned after a group of ships which had been designed on a commercial contract by one of the established shipyards specializing in the construction of tankers; the only changes being made were a slight increase in depth to permit the use of flat sheer through amidships and still obtain approximately the same draft.

All of the other types of ships which had been contracted for on the long range program, and for which contracts were being extended, had been designed to meet the full requirements of the Rules of the American Bureau at the drafts for which the ships were designed.

Even before the war-emergency period, when the planning for large welded ships was first getting under way, the American Bureau had been under considerable pressure from the strong proponents of welding, to permit reductions in the thickness of shell and deck plating, based upon the superior efficiency of end connections and the absence of the complete rings of closely spaced rivet holes as occur at the bulkheads with riveted construction. With the advent of the war this pressure was vigorously renewed not only by the scientific people but also by those in charge of material allocations in an effort to obtain a further spread of the already overtaxed steel-producing facilities of the United States. Fortunately, this pressure was successfully resisted and it can truthfully be said that all of the welded merchant ships involved in the service records which are being made the subject of so much discussion at the present time have scantlings con-

tributing to the over-all longitudinal strength equal to those which would have been provided in riveted ships with no allowances made for superior end connections or the absence of rivet holes.

One of the first steps taken by the Board of Investigation was to re-examine all of the designs and the foregoing statements were completely substantiated. It was felt, however, that there was a possibility of a difference in the over-all behavior between riveted and welded construction and static bending tests were authorized to be carried out and a number of such tests were completed on several different types of vessels. These and a number of other tests which have also been completed in the United Kingdom on directly comparable ships of riveted and welded construction have merely demonstrated that in so far as observed stresses and deflections from applied loads are concerned, the theoretical principles by which the strength of a ship's hull girder is computed are equally applicable to riveted and welded construction.

A ship's hull is a unique structure in the engineering field in respect that it relies upon the heavy plate skin of the structure, formed by the shell and the strength deck plating, to resist the major forces to which it is subjected in service, the framing being of only secondary importance and being designed primarily only to hold the skin up to its work. In order that a ship can efficiently perform the service for which it is intended it is necessary to introduce into the main girder numerous openings, to add internal structure for tank divisions, machinery foundations, etc., and to add external appendages such as bilge keels, or bulwarks as well as superstructures or deck houses for the accommodation of crew, navigating equipment, etc. At the terminals of all of these openings, internal structure or appendages there are introduced structural discontinuities prohibiting uniform straining of the material under the major bending forces and resulting in stress concentrations. In addition, the ship's structure is subjected to many other secondary forces such as those creating torsion when operating in quartering seas, the slamming of heavy seas and those resulting from liquid contents in tanks, thrust from machinery, etc. Through many years of experience with riveted ships, designers have learned generally where they may expect troubles to develop and proper precautions against these have become more or less standard practice. In riveted ships the troubles usually evidence themselves in the form of loosened rivets rather than a fracture in the plate material as in the welded structures. Many items which experience had shown could be treated casually in riveted construction now require very careful attention as to detail when applied to the welded structure.

When reports of casualties in Liberty ships were first beginning to accumulate, there began to be evident a somewhat pronounced pattern which indicated the culpability of certain of the details in initiating the fractures. Outstanding among these which had resulted in casualties of the Group I classification were the corners of the Nos. 3 and 4 hatches, and a cutout which had been made in the top of the sheer strake for the installation of an accommodation ladder. To a lesser extent fractures of varying degree had been found to have apparently originated in bulwark rails, bilge keels, the corners of deck houses and at some ventilator openings near the corners of the deck houses.

Immediately these conditions became evident, action was taken to make corrections to the details at fault and as the program progressed directives were issued from time to time to put certain changes into effect. The original square-

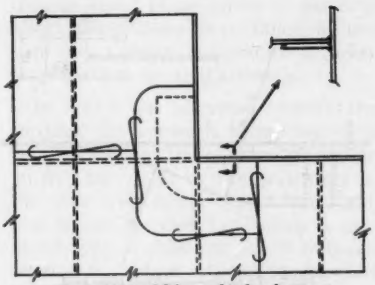

Fig. 1 Original Liberty ship hatch corner

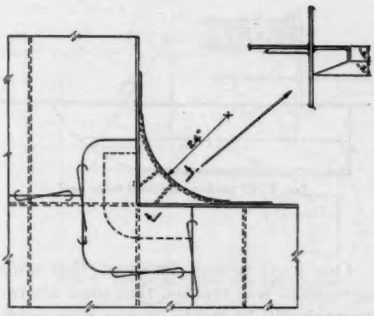

Fig. 3 Reinforcing brackets added to original Liberty ship hatch corner

cut design for the midship hatch corners (Fig. 1) was modified to include a large radius in the plating, this being accomplished in several ways, one of which is shown in Fig. 2. In the ships for which the construction had progressed to such a degree as to make hatch corner changes impracticable, heavy internal reinforcing brackets were required to be installed (Fig. 3). The square cutout for the accommodation ladder was required to be modified (Fig. 4) and in later ships the design of the ladder platform was modified to eliminate the necessity for these cutouts. Bulwarks were redesigned so as to provide attachment to the sheer strake only at widely spaced intervals and cutouts were required to be made in the bilge keels in way of butts (Fig. 5). At the same time these alterations were being made to the Liberty ships, a careful review was made of all of the other types of ships building and where corresponding conditions existed, corresponding alterations were directed.

The number of casualties in the Liberty ships, the causes for which could apparently be traced to these particular details, was felt to be of such proportion that it was decided to make similar alterations to all of the existing vessels of this type and through joint action by the American Bureau of Shipping, the U.S. Coast Guard and the Maritime Commission such directives were issued.

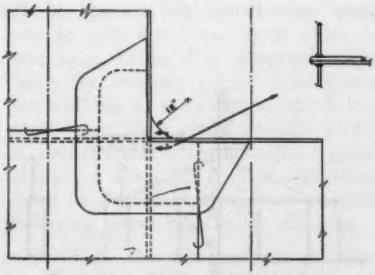

Fig. 2 Improved Liberty ship hatch corner

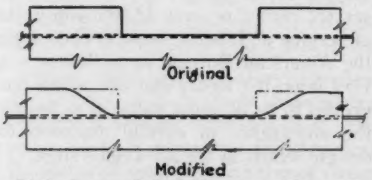

Fig. 4 Accommodation ladder cutout—Liberty ship

Fig. 5 Liberty ship bilge keel

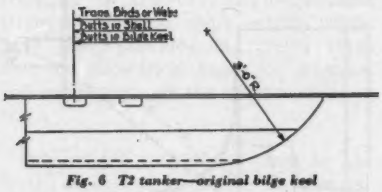

Fig. 6 T2 tanker—original bilge keel

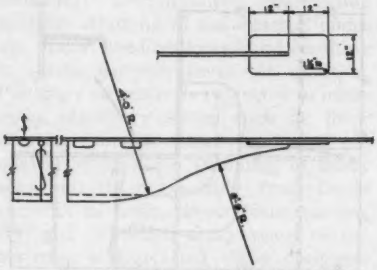

Fig. 7 T2 tanker—modified bilge keel

One must realize, however, that once agreement was reached that some alterations should be made, it was impossible to have these carried out except over a long period of time in view of the large number of ships involved. In the case of the ships under construction it was generally impossible to have the changes in effect until many ships later. The large-scale production of material required for this construction program and the great rate at which fabrication of material and the construction of large preassembled units preceded the actual keel layings, coupled with the fact that changes were authorized on a "not to delay" basis, made it extremely difficult to put into effect even only minor changes in details. As a result there were actually completed and placed in service over 1400 Liberty ships which accumulated 2430 ship-years of service record with the original details. This service record, even though it comprises only a small proportion of the total service record of over 13,400 ship-years of service of Liberty ships in class with the American Bureau, nevertheless is a very imposing figure and one which has proved to be of great value in assessing the importance of careful attention to design details in the all-welded ships.

In the case of the T2 tankers which were beginning to be placed in operation in large numbers in 1943, there were being received reports of Group I and Group II casualties of disturbing nature and steps were immediately taken to catalog and analyze these casualties in the same manner as was being done for Liberty ships and other groups of vessels. Unfortunately, the fractures reported did not appear to fall into any such pattern as did those in the Liberty ships and which pointed to definite improvements which could be made in design details. However, there was evident a quite pronounced grouping at the ends of the bilge keels and steps were immediately taken to modify the bilge keel endings (Fig. 6 and 7). In later years there have been some fractures which are indicated as having had their inception just under the end of a bottom or bilge longitudinal adjacent to a transverse bulkhead and it has now become quite common practice where the heavy through bracket type of connection is used to introduce a large semicircular cutout in the end of the longitudinal in an effort to relieve the hard spot and heavy stress concentration which is believed to exist at the longitudinal ending (Fig. 8). Apart from these two items, the records of the

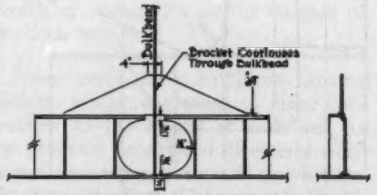

Fig 8 Connections of longitudinal frames at bulkheads

Groups I and II casualties in the large all-welded tankers have failed to provide any definite indications of necessary changes in design details.

In 1942 it was becoming apparent that through the emphasis being placed on standardization there were being acquired too great a preponderance of the slow work-horse type Liberty ship and it was decided to develop a new, faster type of ship and put it into production in certain selected yards which had been building the Liberty ships. All of the experience which had been acquired in the construction and operation of the Liberty ships was brought to bear in the planning of this new type which was designated the Victory ship. The structure was arranged so as to lend itself readily to the prefabrication of large subassemblies up to the capacity of the handling equipment in the shipyards and careful attention was paid to the locations of the field joints so as to avoid critical locations and to provide the greatest accessibility for welding. Details which had proved to be troublesome in the Liberty ships were carefully redesigned. As an example it was decided that the hatch corners should be cut with a large radius and that the use of doublers or insert plates should be avoided. The widths of plates available for these new ships were known and the width for the hatches was established so that an increase in the thickness of the plating at the corners was provided by the use of a heavier single plate comprising the full width of the plating strake (Fig. 9). It might properly be said that these ships were the first large cargo ships designed exclusively for welding, taking into account the facilities of the yards in which they were to be built, and available widths of plating strakes. Shortly after, a group of smaller ships 321 ft. long and designated as the C1-M type were designed following somewhat similar planning.

Prior to the development of plans for these vessels, concern had been felt

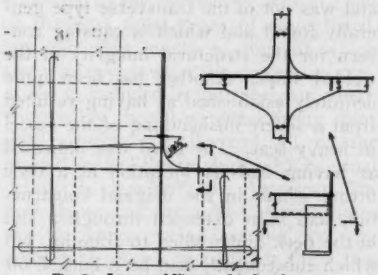

Fig. 9 Layout of Victory ship hatch corner

over the number of fractures originating in the upper parts of the Liberty ship hulls, three of which had resulted in complete failure of the hull and four of which had resulted in abandonment of the vessels. Directives had been issued calling for the fitting of a riveted seam strap just outboard of the line of the hatches and for a riveted gunwale connection at the Upper Deck throughout amidships, on all of the Liberty ships under construction where the alterations could be made without delay. Subsequently orders were issued requiring the installation in existing ships of a riveted connection either by cutting the stringer plate clear of the sheer strake or by cutting a slot in the sheer strake plate covering same with a double riveted strap. In realization of the possible benefits of these so-called crack arresters it was decided to incorporate riveted gunwale angles into the original design of the Victory and C1-M ships.

These ships have performed excellent service, 414 of the Victory ships having amassed a service record of 2450 ship-years while in class with the American Bureau with only 12 casualties of Group II having been reported. Up until November 1951 there had been no casualties of Group I reported but during the fall and winter of 1951-52 there were reported four such casualties. One of these was most unusual having consisted of a long fracture extending generally fore and aft in the bottom shell

and was not of the transverse type generally found and which is causing concern for the structural integrity of the welded ships. Another has been quite definitely established as having resulted from a severe mishandling of the vessel in heavy seas. The third was indicated as having had its inception at a deck fitting which in the original construction had been extended through a slot in the deck and welded to framing, but which subsequently had been burned off flush with the deck. Very little is known about the fourth casualty since the vessel and all hands were lost. According to reports prior to the abandonment of the vessel, the fracture extended vertically in the side shell plating in the engine room for about 16 ft., but the reports give strong indications that the loss of the vessel was not occasioned by this crack but rather more from other causes. The C1-M vessels accumulated a service record of 1020 ship-years with only two casualties reported. Both of these are classed as Group I, extending completely across the deck on one side at about the middle of the length of a hatch opening.

These records are worthy of particular notice when it is considered that these ships were built under wartime conditions, using materials no better than those provided for the Liberty ship program. It is true that they came along late in the war construction program and that the concentrated educational campaigns as well as the great publicity given to the possible disastrous results of poor workmanship may have been beginning to have effect in improving workmanship. Likewise a larger proportion of the service record for these vessels was acquired after the war than is the case with the Liberty ships. Notwithstanding these favorable factors, however, it is felt that the service records of these two classes of ships are an indication of what can be done by careful designing and planning, taking full advantage of the lessons learned from previous experience.

EFFECT OF RIVETING

To just what extent the fitting of the riveted gunwale connections contributed to the improvement of the service record of these ships as compared to the Liberty ships is one on which we can only speculate. When the service records of the Liberty ships were first being accumulated, it soon became apparent that the ships built by the Bethlehem-Fairfield yard with riveted shell seams were showing a vastly superior record in so far as hull fractures were concerned. These ships were identical in design to the all-welded Liberty ships having completely welded Upper Decks with welded gunwale connections, the same square hatch corner details, etc., and it was not that the riveted seams stopped the cracks from spreading but the cracks themselves just did not occur with the same frequency. This early noticeable trend has continued throughout the continually increasing service records, and it appears that these ships built with the riveted seams are less susceptible to fractures originating from defective welds, poorly designed details, etc. When the studies of casualty records were beginning to show a need for improvement in some of the design details, the changes requested to be made to hatch corners, sheer strake cutouts, and bilge keels were made equally applicable to the Bethlehem-Fairfield ships and when these alterations were made retroactive to be applied to the existing ships, the Bethlehem-Fairfield ships were also included. The fitting of crack arrestors on the existing ships of this type was not required but a few of the last ships under construction were fitted with the strap on the deck just outboard of the line of the hatches and with a riveted

gunwale angle. However, this was done on only a very few of these ships and it is impossible to establish whether or not this one change on the relatively few ships involved has had any influence.

Accordingly, for statistical purposes it has been assumed that the Liberty ships can roughly be divided into six broad classifications as indicated by lines (1) to (6) in Table 1. This table has been compiled to show the service records of all of the different types of oceangoing merchant ships built to class with the American Bureau of Shipping in quantities since just prior to the war and in which welding was used to any great extent. However, there have been omitted the records of two comparatively small groups of refrigerated cargo ships since it is generally accepted that a number of the casualties reported in these ships resulted from the abnormally low temperatures to which the steel was subjected. For purposes of comparison the figures for the all-welded ships have been set apart from those for the ships with some riveted longitudinal joints and in the latter cases the number of such joints has been indicated. There is no differentiation as to the method of attaching vertical side frames; ships which have riveted side frames but which are otherwise all-welded are classified as being all-welded. In the table are given the number of ships of each group contributing to the service record and the number of ship-years comprising the record. It should be noted that in some types the same ship may have contributed to the service record of more than one group owing to the classification as to type having been changed. For instance, an all-welded Liberty ship which commenced service with original details, then later had the improvements made and still later had riveted crack arrestors installed will appear in the count of 1220, 1890 and 1057 ships contributing to the service records of each of the first three types of ships listed, but only that length of time at which she was operated in the respective condition is included in the ship-year count. Since all of the all-welded Liberty ships with original details and all of the riveted seam Liberty ships with original details in class with the American Bureau have had improved details there are no longer being accumulated any additional service records for these two types and the figures given are final. With very few exceptions all of the all-welded Liberty ships with improved details have had riveted crack arrestors fitted so that the figures for this type are very near to being final. All of the T2 tankers in class with the Bureau have had at least four riveted crack arrestors since 1948 so that the figures for the all-welded T2 tankers became final at that time.

A study of the figures contained in this table can lead to many interesting speculations but it is not the author's intention to draw any positive conclusions but only to make available the facts as they have been accumulated in the records of the American Bureau of Shipping. It is realized that statistical tables can be very misleading particularly if one has not been sufficiently closely associated with their development to fully appreciate their limitations. However, analysis of the figures for the Liberty ship groups certainly appears to bear out the trends which were noticed early in the accumulation of service records concerning the probable beneficial effects of the riveted seams. It should be noted that in 2100 ship-years of service there occurred in the all-welded Liberty ships with original details 408 casualties of Group I and Group II type, a rate of 19.45 such casualties per 100 ship-years. For the Bethlehem-Fairfield ships, practically identical except for the riveted shell seams, there occurred 17 such casualties

Table 1

Number of Casualties and Length of Service up to March 31st 1952 for Vessels over 300 ft in Length Built to Classification with the American Bureau of Shipping from 1938 until the Adoption of New Steel Specifications (1948). (Note 5)

Line Number	Type of Vessel	Length (Approx)	Amount of Riveting	All-Welded Ships: Number of Ships completing Service	All-Welded Ships: Length of Service Period (Ship-years)	All-Welded Ships: Number of Casualties Group I	All-Welded Ships: Number of Casualties Group II	All-Welded Ships: Total No of Casualties Group I and II	All-Welded Ships: No of Cas. G-I & G-II per 100 Ship-years	Ships with some Riveting*: Number of Ships completing Service	Ships with some Riveting*: Length of Service Period (Ship-years)	Ships with some Riveting*: Number of Casualties Group I	Ships with some Riveting*: Number of Casualties Group II	Ships with some Riveting*: Total No of Casualties Group I & II	Ships with some Riveting*: No of Cas. G-I & G-II per 100 Ship-years	Line Number
1	Liberty Ships with Original details	441'6"	None (1)	1238	2198	88	320	408	18.65							1
2	with Improved details		None (1)	1894	2829	14	81	95	3.35							2
3	with Improved details		Gunwale Connection (2)							1087	4438	21	91	112	2.51	3
4	with Improved details		Gunwale Connection (2)							497	2054	18	50	68	3.27	4
5	with Original details		All Shell Seams							208	536	1	16	17	3.15	5
6	with Improved details		All Shell Seams (3)							313	1713	2	42	44	2.57	6
7	Victory Ships	436'6"	Gunwale Angle							414	2454	4	12	16	0.65	7
8	C1-M Ships	321'6"	Gunwale Angle							218	1026	2	0	2	0.20	8
9	Cargo & Passenger Vessels	365'	Side Shell Seams & Gunwale							9	41	0	0	0	0	9
10		390'	None	96	190	1	8	9	4.74							10
11		390'	All Shell Seams							19	109	0	8	8	7.36	11
12		395'	None	18	36	0	6	6	8.38							12
13		395'	All Shell Seams							85	463	3	21	24	5.18	13
14		400'	All Shell & Deck Seams							4	41	0	2	2	4.88	14
15		425'	Gunwale Angle							19	89	0	0	0	0	15
16		425'	Side Shell Seams & Gunwale							6	84	0	0	0	0	16
17		427'	None	3	29	1	1	2	6.90							17
18		431'	Gunwale Angle							6	41	0	0	0	0	18
19		431'	Side Shell Seams & Gunwale							3	12	0	0	0	0	19
20		435'	None	117	589	5	9	7	1.19							20
21		435'	Side Shell Seams							64	478	3	6	8	1.67	21
22		435'	All Shell Seams							30	299	0	12	12	4.01	22
23		443'	None	30	67	2	4	6	8.95							23
24		443'	Gunwale Connection & Bil. Strap							1349	94	5	5	7	7.89	24
25		443'	Gunwale Angle & Horn Casting							5	59	0	2	2	3.38	25
26		450'	All Shell Seams							21	184	0	1	1	0.54	26
27		465'	None	132	760	6	40	46	6.04							27
28		465'	Gunwale Connection							3	16	0	0	0	0	28
29		465'	Side Shell Seams							5	41	0	0	0	0	29
30		465'	Side Shell Seams & Gunwale							11	65	0	0	0	0	30
31		465'	All Shell Seams							18	104	1	1	2	1.92	31
32		465'	All Shell & Bil. Seams & Gunwale							7	87	0	0	0	0	32
33		496'7"	None	96	218	1	3	4	4.13							33
34		496'7"	Riveted Gunwale							31	158	1	1	2	1.27	34
35		523'	Side Shell Seams	—	—	—	—	—	—	11	88	0	0	0	0	35
36		523'	All Shell Seams							10	71	0	0	0	0	36
37	Sub-Totals for Cargo & Pass. Vessels		All-welded Ships	3698	6823	113	472	587	8.60							37
38			Ships with Riveting Added							1078	4531	23	96	119	2.62	38
39			Ships built with some Riveting							2021	10852	27	178	204	1.88	39
40	T-2 Tankers	505'	None	508	1933	28	97	77	6.53							40
41			Riveted Straps or Girders							998	1778	21	43	64	3.61	41
42	T-1-M Tankers	509'	None	29	117	1	0	1	0.85							42
43			Riveted Straps							3	8	0	0	0	0	43
44		450'	None	8	18	1	0	1	5.55							44
45		450'	Side Shell & Deck Seams							4	41	0	0	0	0	45
46		487'	All Shell & Deck Seams							5	38	0	1	1	2.63	46
47		487'	Side Shell & Deck Seams							34	219	0	1	1	0.47	47
48		500'	None	8	50	0	6	6	12.00							48
49		500'	Side Shell & Deck Seams							14	135	2	7	9	6.67	49
50		505'	All Shell & Deck Seams							4	28	0	0	0	0	50
51		505'	Side Shell & Deck Seams							2	20	0	0	0	0	51
52		521'	None	23	109	3	8	11	7.34							52
53		521'	4 or 8 Riveted Straps							18	57	1	3	4	7.02	53
54		825'	All Shell & Deck Seams							31	276	0	4	4	1.45	54
55		541'	None	5	31	0	2	2	6.44							55
56	Sub-Total for Tankers		All-welded Ships	569	1948	33	85	118	6.05							56
57			Ships with Riveting Added							505	1837	22	51	73	3.96	57
58			Ships built with some Riveting							94	754	2	13	15	2.01	58
59	Grand Totals		All-welded Ships	4267	8671	146	557	705	8.13							59
60			Ships with Riveting Added							1577	6368	45	147	192	3.01	60
61			Ships built with some Riveting							2115	10938	31	188	219	1.99	61

Note 1 In some cases frames were riveted but in all other respects vessels were entirely welded

Note 2 In some cases vessels also had a riveted seam strap in upper deck

Note 3 In some cases vessels also had a riveted gunwale angle and a riveted seam strap in upper deck

Note 4 The riveting in these vessels was added after the vessels had had some service as all welded vessels

Note 5 In this Table there have been excluded two small groups of special refrigerated type vessels

in 330 ship-years of service, a rate of only 5.15 per 100 ship-years. It should also be observed that of the 408 casualties in the all-welded ships, 88 or more than one in five included fractures which had propagated to such an extent that the casualty was classified as Group I, whereas in the ships with the riveted seams only one out of 17 included a really serious fracture. Worthy of note is the fact that by improving the details in the all-welded vessels the rate of occurrence of casualties was reduced from 19.45 to 3.62 casualties per 100 ship-years of service, a rate of reduction of better than 5 to 1 whereas in the ships with riveted seams the rate was reduced from 5.15 to 2.57, just 2 to 1, which appears to indicate the greater susceptibility to poorly designed details in the all-welded ships. In these two types of ships with the improved details the probability of fractures propagating to a dangerous degree in the ships with riveted seams still appears to be decidedly less than in the all-welded ship. It might readily be expected that fractures in the shell where the seams are all riveted would be limited in extent but the majority of the casualties reported in both types of ships comprised fractures in the Upper Deck where the riveted seams were not present.

It is possible that these service records may have been influenced to some extent by the fact that all of the Liberty ships with riveted seams were built in only one yard and that in that particular yard nearly all of the plate material came from one supplier. An investigation which was made by a special welding advisory group during the course of the construction program, and which covered all phases of the shipyard organizations, procedures and practices affecting the quality of workmanship in all of the yards participating in the program, failed to disclose any pronounced superiority in the Bethlehem-Fairfield yard and such investigations of the quality of the steel supplied to that yard as have been made have likewise failed to support any belief that the steel used was in any way superior to that being supplied to the other yards building Liberty ships. When the superior service records of these ships with the riveted seams first became apparent, it became the practice to assign them to the more arduous service routes so that if there is any influence whatever, resulting from trade routes, such influence should properly be expected to be against these ships.

It is perhaps unfortunate that we do not have any other large groups of ships which are directly comparable, except for some riveted connections, and which have compiled a sufficiently large service record to be of statistical value. It is true that the service records for the all-welded Liberty ships with improved details and those for the T2 tankers show some improvement after these two types were fitted with riveted crack arrestors, but since the large bulk of the Liberty ships and all of the T2 tankers comprising these groups had several years of operation under wartime conditions before the arrestors were fitted it can reasonably be expected that poor workmanship might have disclosed itself in the form of casualties and that the correction of the more serious defects as disclosed, coupled with what is believed to be the less arduous services in peacetime, would have resulted in some improvement in the service records even if the arrestors had not been fitted.

Just prior to and during the war years and for a few years immediately following the war there were built in the shipyards of the United States 67 all-welded seagoing tankers of over 300 ft. in length in addition to the T2 tankers. There were also built 94 large tankers in which welding had been used extensively but in which riveting had been used in varying degrees. While not duplicates of the T2 tankers, all of these

vessels have marked similarity. They are all longitudinally framed and include details corresponding to those which have been under suspicion as having contributed to some of the casualties in the T2 tankers. A number of these vessels have plate and angle bulkheads instead of the corrugated bulkheads as fitted in the T2 tankers, but there is no evidence whatever that the type of bulkhead construction has any influence on the creation of fractures comprising a Group I or Group II casualty. A large proportion of these vessels was built under the pressure of wartime urgency and for all of these vessels the hull steel supplied was of no better quality than that used in the T2 tankers. The service records for the 67 all-welded tankers combined with those of the T2 tankers prior to being fitted with riveted straps are given in line 56 of the table. The records for the 94 vessels which had been built with some riveting are given in line 58 and we find very much the same pattern of relatively superior service records as is shown by the Liberty ships having riveted shell seams. It is interesting to note that of the 15 casualties reported in the tankers built with riveting, 12 of these involved fractures in butt welds where workmanship was clearly at fault, there being no suspicion of a design detail having contributed to the casualty. The details of the remaining three casualties have never been clearly established.

These data appear to support statements which have been made in the past by a number of experts in the shipbuilding field to the effect that, in the light of our present knowledge as to the fundamental causes of fracture in welded ships' hulls, a judicious mixture of welding and riveting may be the most sound approach. There are many who deplore the now almost universal practice of including several riveted longitudinal connections in the shell and decks of the modern large otherwise all-welded ships. These joints are often termed crack-stoppers and they are often referred to as representing a defeatist attitude on the part of shipbuilders, it being claimed that all efforts should be directed toward preventing cracks from initiating to the end that it should not be necessary to provide these joints to limit their extent. The author can have no quarrel whatever with this philosophy but it is quite possible that the inclusion, in the original construction, of a number of riveted longitudinal connections may, in addition to providing a means to stop a crack, once started, also have some beneficial effect on the liability of the starting of a crack. There are some who maintain that the punching or drilling of holes for rivets near the edges of plates or in a heavy riveted gunwale angle seriously weakens these members at important locations. There is no doubt that these holes do detract from the strength in tension but in all of the service records of ships built with riveted seams or gunwales, there have never been any indications that this weakening has been the cause of a failure.

WORKMANSHIP

It is almost impossible to separate design from workmanship since these two phases of the problems with which we are confronted are inextricably related. In nearly every case where design details have been considered to be a contributing factor in the initiation of a fracture, the question of workmanship has also been involved. The original square-cut design of the hatch corners in the Liberty ships, while admittedly not the most desirable design, probably would not have caused so many fractures had the workmanship been of the

highest quality in every case. Generally, in the examination of those fractures which have apparently had their inception at discontinuities such as occur at the ends of bilge keels, the ends of longitudinal frames adjacent to bulkheads in tankers or at the connections of fittings or fashion plates to the sheer strakes, it has been found that the workmanship is of very doubtful quality, the welding often being found to be improperly fused or accompanied by deep undercutting. Designers can, to a certain extent, develop design details in which the susceptibility to poor workmanship can be reduced but there is still a great dependency on the quality of workmanship in order that there may be produced a completely trouble-free structure. In the Liberty ships alone out of a total of 735 casualties reported, 132 or approximately 18% were indicated as having had their inception in a defective weld in a butt or seam, where there was present no structural discontinuity or design detail which could possibly have contributed to the failure. In the T2 tankers over 50% of the casualties have had their origin in welds which are entirely clear of any discontinuities and in the tankers with some riveted seams this ratio is still higher.

It is most difficult to point to any positive measures which have been taken to insure none but the best welding. In general, shipyards have tightened up on the requirements for qualifying welders, there have been made available and put into general use improved methods of inspection such as X-ray or Gamma-ray methods, but the latter admittedly can only be used as a spot-check measure, exploring only a few of the more critical areas, and their benefits depend to a large extent on the psychological effect on the individual welder.

During the war shipbuilding program, due to the tremendous expansion of the shipbuilding industry in the United States, the recruiting of a sufficient number of competent inspectors to serve the shipyards themselves, the owners, the government regulatory bodies and the Classification Societies to the same extent as is done in normal times was an impossible task. The practice of working the plants on an around-the-clock basis undoubtedly had an adverse effect on the quality of workmanship. The urgency with which the ships were required to be produced occasioned an attitude on the part of the few available inspectors toward being liberal in their judgment as to what should or should not be accepted. Coupled with the fact that many of the welders being employed had had little or no prior experience, it is not surprising that we should have uncovered so much defective workmanship, but it is confidently believed that we can and have profited by the lessons learned.

In the shipyards today, the supervision is far more extensive and more severe in judgment; many of the yards have elaborate positioning equipment and provide better working facilities, all of which should have a decided effect on the quality of workmanship, but we are still dependent to a great degree on the integrity of the individual welder to produce under working conditions the high quality welds which he has shown he can produce when passing the qualification tests. There is a great deal that needs to be done toward reducing this dependence on the individual and it is a challenge to the welding industry in general to continue to strive to make available to users improved equipment, electrodes, etc., which will make the production of good sound welds more or less automatic, to the end that even an indifferent welder will find it difficult to produce a poor weld. There are being brought into prominence new improved electrodes such as those of the lime-coated, low-hydrogen variety. These have shown great promise for certain applications, but opinion in

American shipyards is still against their widespread adoption on account of questions regarding usability. It is all very well to demonstrate what a certain piece of equipment is capable of producing but what concerns those of us in the shipbuilding field, as well as those connected with the production of other large field-welded structures, is not so much what the equipment can do under controlled conditions but what it actually does do in actual service.

MATERIALS

It is in the field of materials where the most positive steps have been indicated as being practicable to undertake in an effort to guard against the repetition of the serious casualties which have occurred in the war-built vessels. As mentioned earlier in this paper, in the report presented by the committee of experts appointed by the American Bureau of Shipping to investigate the failure of the T2 tanker *Schenectady*, there was raised the question as to the adequacy of the then existing specifications for hull steel to provide proper materials for welded construction. There was no fault to be found with the steel involved in the fracture when compared with material which had always proved to be satisfactory for use in riveted ships and it was quite apparent that in the large welded structures there had been introduced conditions which made the notch toughness of the steel of far greater significance than had been the case in riveted construction. When the Board of Investigation of the Design and Methods of Construction of Welded Steel Merchant Vessels commenced to function, one of the early steps taken was the initiation of research projects on this subject. Vast sums of money were spent on projects in the various laboratories of universities in the United States but no specific recommendations for a revision in specifications were produced. When the Board made its final report in 1946 a great deal of research in this and other fields had not been completed and some of the work in hand had already pointed to the need for continued study and the initiation of new projects. Accordingly, the Board recommended that an organization be set up to continue this work. Acting upon this recommendation, the Secretary of Treasury, to whom the functions of the Coast Guard had been restored at the close of the war, appointed a committee known as the Ship Structure Committee comprised of representatives from the same agencies as had been represented on the Board. Under the auspices of this committee a large amount of research work has been and still is being carried out aimed at the development of a new ship steel specification. Liaison has been maintained with corresponding groups working on the same subject in the United Kingdom and elsewhere and all of this work has been highly publicized and made available to those interested throughout the world. Concurrently with this research work, a program of investigation of steel removed from fractured ships was inaugurated under the direction of the Board and later the Ship Structure Committee, and at the same time we in the American Bureau undertook a paralleling program in our own laboratory. Under these two programs steel which had been involved in casualties on nearly 100 ships has been subjected to most exhaustive tests and there has been developed a rather well-defined pattern indicating that material where a fracture originates usually shows a relatively low notch toughness and a high transition temperature. Where a

fracture terminates in parent metal, the material shows a relatively high degree of notch toughness with a low transition temperature, and material through which a crack propagates usually falls in between. Agreement has not yet been reached as to a proper test for specification purposes nor as to quantitative values related to any particular test, but in appreciation of the work which had been completed, the American Bureau of Shipping formed, in its organization of Technical Committees, a Special Sub-Committee on Materials. Appointed to this committee were leading experts from steel manufacturers, shipbuilders and users of steel in other fields. All of the data available were carefully reviewed by this committee and, after a number of meetings, agreement was reached in 1947 to modify the Rules to include additional specifications for hull-steel plates which in the opinion of the committee would successfully screen out the more notch-sensitive steels.

Inasmuch as there never had been any record of failure in small ships, barges, etc., which did not require the use of heavy plates, or in structural shapes, and in recognition of the well-established fact that for steel plates rolled from any one heat, the transition temperature and notch sensitivity increase with an increase in thickness of the rolled material, it was decided that the specifications should be set up to cover three grades of steel.

The recommendations of this committee were reviewed by the Committee on Naval Architecture and later by the Main Technical Committee of the Bureau, and in November 1947 they were approved and officially made a part of the requirements for classification with the Bureau. In subsequent years some minor modifications have been made but the present specifications which are repeated in the following are substantially the same as those agreed upon in 1947.

STRUCTURAL STEEL FOR HULLS

Process of Manufacture: The steel used in the construction of the hulls of vessels shall be made by either or both the open-hearth or electric-furnace process.

Chemical Composition—Ladle Analysis: (*a*) Except as specified in paragraph (*b*) the material shall conform to the requirements of Class A as to chemical composition.

(*b*) Plates over ½ and up to 1 in., inclusive, in thickness shall conform to the requirements of Class B as to chemical composition. Plates over 1 in. in thickness shall conform to the requirements of Class C as to chemical composition.

	Class A	*Class B*	*Class C**
Carbon, max. %	..	0.23	0.25
Manganese, %	..	0.60-0.90	0.60-0.90
Phosphorus, max. % †	0.04	0.04	0.04
Sulfur, max. %	0.05	0.05	0.05
Silicon, %	..	..	0.15-0.30

* Plate steels produced to the requirements of Class C shall be made with fine grain practice.
† Where steel is made by the acid process the maximum per cent phosphorus permitted may be 0.06.

Tensile Properties: (*a*) The material, except as specified in paragraph (*b*), shall conform to the following requirements as to tensile properties:

	Structural steel	*Rivet steel and steel for cold flanging*
Tensile strength, psi	58,000-71,000	55,000-65,000
Yield point, min. psi	32,000	30,000
Elongation in 8 in., min. %	21	23
Elongation in 2 in., min. %	22	..

(*b*) Flat-rolled steel 5/16 in. and under in thickness, shapes less than 1 sq. in. in cross section, and bars, other than flats, less than ½ in. in thickness or diameter, need not be subjected to tension tests.

(*c*) For material over ¾ in. in thickness or diameter, a deduction from the percentage of elongation in 8 in. specified in paragraph (*a*) of 0.25% shall be made for each increase of 1/32 in. of the specified thickness or diameter above ¾ in. to a minimum of 18%.

(*d*) For material under 5/16 in. in thickness or diameter, a deduction from the percentage of elongation in 8 in. specified in paragraph (*a*) of 2% shall be made for each decrease of 1/32 in. of the specified thickness or diameter below 5/16 in.

Bending Properties: The bend-test specimen shall stand being bent cold through 180 deg. without cracking on the outside of the bent portion to an inside diameter which shall have the following relation to the thickness of the specimen:

	Ratio of bend diameter to thickness of specimen	
Thickness of material	*Structural steel*	*Rivet steel and steel for cold flanging*
¾ in. and under	1	Flat on itself
Over ¾ to 1¼ in., inclusive	2	1
Over 1¼ in.	3	2

It should be noted that the specifications for Class A steel covering all shapes and plates not exceeding ½ in. in thickness do not differ materially from the specifications which were applicable to all hull steel during the war construction program. The specifications for Class B steel covering plates over ½ in. but not exceeding 1 in. in thickness, however, have been amplified to include a limit on carbon and a specified range for manganese while those for Class C, covering plates over 1 in. in thickness have, in addition, a silicon requirement and an added requirement that the steel shall be made with fine-grain practice such as will insure a fully killed fine-grain steel.

The reception which was accorded to these new specifications when they were first announced was most gratifying. At the time there were actually under contract or in the process of being contracted for in the United States shipyards a large number of tankers of

26,000 to 30,000 tons deadweight. These were to be primarily of welded construction having only a few riveted seams on each side and some of the owners and builders were still apprehensive of welded construction even with the few riveted seams. Even though these ships were under contract at fixed prices the builders and owners through mutual agreement adopted the new specifications and accepted the extra cost resulting therefrom so that for all of the vessels for which the heavy plates had not as yet been produced, steel in accordance with the new specifications was obtained. As a result there are now in operation more than 40 of these large tankers in class with the Bureau in which the improved steel was used. These have compiled only a relatively small service record totaling only a little over 80 ship-years but we have not as yet received a single report of a fracture comprising a Group I or Group II casualty.

The Bureau has never maintained that these specifications are the last word on the subject and it is recognized that some notch-sensitive material may still leak through. Research on this problem is still being pursued vigorously and a continuous program of random checking of material as actually being supplied to shipyards has not yet disclosed any particularly undesirable material furnished under the new specifications. It is probable that as the sizes of ships increase, involving the use of heavier material it may be found that the present specifications will require to be supplemented for the extremely thick plates by additional chemical controls or by heat treatment of the finished material.

The steel specifications adopted by the Bureau have received widespread recognition, and in a number of fields of welded structures other than shipbuilding use, has been made of these specifications in an effort to overcome difficulties which have been experienced in those fields. It is particularly worthy of note that in the years following this action taken by the American Bureau of Shipping, the other leading Classification Societies have taken similar action. In some cases the method of approach is somewhat different, but they have all aimed at the same objective, i.e., the obtaining of plates of good notch toughness at low temperatures. In some of the other Societies' Rules, the supplementary specifications are specifically mentioned as being applicable only to welded construction. There is no doubt but that the problem of notch toughness of plates was brought into prominence with the advent of welding and that previous specifications had proved adequate for riveted ships but the Committee of the American Bureau decided that welding was here to stay in the construction of ships, and that the problems of housekeeping would be almost impossible of solution if we were to have two specifications for steel, particularly in repair yards.

CLOSURE

This is not the type of paper which lends itself to a brief summary in the form of conclusions. It has been the author's intention to merely set forth the background of experience acquired with welded construction in the shipyards of the United States prior to the war construction program, the experience acquired during that program and with the ships built during that emergency period in the belief that many valuable lessons can be learned from the experience. We have learned that designers must continually strive toward the development of details which will lend themselves readily to good sound workmanship and that with welded construction careful attention must be paid to what might have been considered to be only a very inconse-

quential and most trivial detail in riveted construction. We have learned the important part that workmanship plays in the creation of the trouble-free welded structure. Any welds which are in any way under suspicion should be carefully explored and those of doubtful quality should be renewed. Careful fitting is a necessity since experience has demonstrated the possible disastrous results of excessive forcing of subassemblies or the use of excessive welding to make up extra wide welded joints. We must adopt steel specifications which will effectively screen out highly notch-sensitive material, and even though these may entail some added cost we must accept this added cost in the realization that it is justified by the protection gained against fractures.

One thing we must guard against is complacency. One often hears a certain owner or builder decry the emphasis which is being placed on design, workmanship and material, maintaining that he has never had any difficulties with any of the ships owned by him or built by him. After all, there have been only a comparatively small number of serious casualties in the welded ships when related to the vast numbers of such ships in service. There are several thousands which have given completely trouble-free service in so far as the hull structure is concerned but, unfortunately, it has never been possible to establish just what was done in the trouble-free ships and was not done in the ships which suffered casualties and vice versa.

The author can only state that he has the greatest confidence in the ability to safely employ this comparatively new and most desirable method of joining steel parts, provided we are all prepared to pay careful heed to the experience so far acquired. He is completely willing to subscribe to the opinion expressed in the report of the Board of Investigation of the Design and Methods of Construction of Welded Merchant Vessels and which has of late been repeated by several authorities, to the effect that with proper detail design, high quality workmanship and a steel which has low notch sensitivity at operating temperatures, a satisfactory all-welded ship structure may be obtained.

THE INTERNAL REACTION ENGINE

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THE AUTHOR

is a native of El Paso, Texas, and a graduate of the U. S. Naval Academy in the class of 1944. During World War II he served in the gunnery department of USS *Ranger* and USS *Quincy*, and during the early post-war years was communications officer of USS *Mindoro*. He resigned from the Navy in 1947, took a postgraduate course at Rice Institute, and is presently employed in the A&OS Division of the General Electric Company in Schenectady, New York.

A general survey of transporting machines reveals that they function on the principle that for every action there is an equal and opposite reaction. Heretofore there have been two major types of such machines: 1) Those in which the reaction is manifest in some external substance such as the earth, sea or atmosphere. Automobiles, ships, propeller-driven aircraft fall in this category. 2) Those in which the reaction is manifest in an exhausted substance, usually high velocity gases. Jet aircraft and rockets fall in this category.

There is yet a third type of machine which is theoretically possible. In such a machine the reaction is manifest entirely within the body of the machine itself. Such a machine requires no connection with the external world and may be totally enclosed and hermetically sealed if desired.

It is highly unlikely that a machine of this type would be practical for earth travel. However with the advent of space travel the features of the internal reaction engine may become important, particularly the feature of high theoretical efficiency.

Considered from the standpoint of momentum the perfect rocket has a maximum efficiency of only fifty per cent. This is because for every unit of forward momentum possessed by the rocket there must be a corresponding unit of backward momentum possessed by the rocket exhaust. The energy of the exhaust is not recoverable and is forever lost from the craft.

Since momentum must be conserved it would not seem feasible that motion of a machine could be obtained without a corresponding negative momentum of some exhausted substance. With machines based upon Newtonian mechanics this is true. However with the employment of relativistic mechanics the internal reaction engine becomes possible.

Consider the block diagram in figure 1. This is a representation of the basic units of the internal reaction engine which functions as follows: The posi-

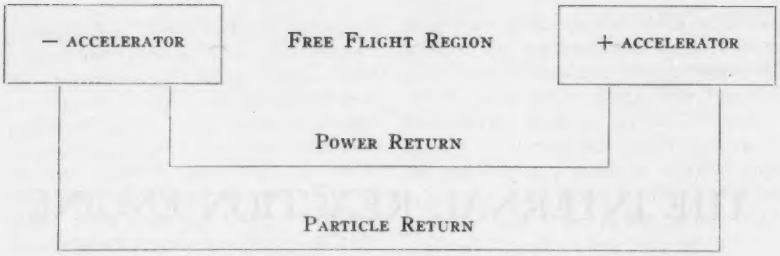

Figure 1—Basic Units of the Internal Reaction Engine.

tive accelerator accelerates particles which pass at a very high velocity across the free flight region and enter the negative accelerator where they are brought to a stop. The energy extracted from the particles by the negative accelerator is fed back, via power return, to the positive accelerator. The particles themselves are returned at a very low velocity, via particle return, to the positive accelerator. The process is continuous.

In such a closed loop system there are two criteria for motion.

I. The positive accelerating force must exceed the negative accelerating force, and/or

II. The summation of the particle momentums in the free flight region must exceed the summation of the particle momentums in the particle return path.

The second criterion only will be considered. From this criterion it is clear that motion will result if in the free flight region particles are moving at a velocity approaching that of light and if in their return path they are moving at a velocity negligible compared to that of light.

In mathematical form the momentum of the loop, and therefore of the machine as a whole, is as follows:

$$\text{Momentum} = \frac{NMV_1}{\sqrt{1 - V_1^2/C^2}} - \frac{NMV_2}{\sqrt{1 - V_2^2/C^2}} \quad (1)$$

where

N is the number of particles involved

M is the rest mass of each particle

V_1 is the particle velocity in the free flight region

V_2 is the particle velocity in the return path

C is the velocity of light

It is seen that if V_2 is considered to be negligible compared to C then,

$$\text{Momentum} = \frac{NMV_1}{\sqrt{1 - V_1^2/C^2}} - NMV_2 \quad (2)$$

It may be further assumed that

$$NMV_1 = NMV_2$$

thus, approximately

$$\text{Momentum} = NMV_1\left(\frac{1}{\sqrt{1 - V_1^2/C^2}} - 1\right) \quad (3)$$

In practice it is probable that electrons would be most ideal for the application due to the availability and the relative ease with which they may be controlled. In such a case the two accelerators would be linear electron

accelerators, the free flight region an evacuated chamber and the particle return path simply a large conductor returning the electrons to the positive accelerator in the form of current.

Because of the small mass of the electron it is clear from equation (3) that if appreciable momentum is to be obtained either N or V_1 must be extremely large. Possibly the greatest effectiveness could be obtained by increasing V_1. At the present time this is difficult to do using known engineering methods. However there is no reason to believe that present linear accelerators give us ultimate performance and certainly further development can be expected. The internal reaction engine awaits such development.

If and when adequate linear accelerators are developed the internal reaction engine will operate at an efficiency approaching the efficiency of the accelerators. There will be no exhaust waste.

Aside from the efficiency the device has another remarkable characteristic which may or may not be an advantage. Since the machine has at all times a zero net momentum it will not coast. Control is positive. As soon as the accelerators are turned off motion ceases. This feature might actually be dangerous since in the event of power failure during flight a very sudden stopping will occur. On the other hand such positive means of controlling motion may be of great value since power for stopping is immediately available regardless of the velocity reached. A further advantage of course is the feature of total enclosure and general independence of the external world.

While it may not be proven at this time that the internal reaction engine is a practical machine, certainly it should be duly considered as we plan and build the strange new ships which will carry us in our explorations out into the vast sea of space.

FIRE PROTECTION IN PASSENGER SHIPS

ACKNOWLEDGMENT

This is an abridged version of a paper presented at the Autumn Meeting of The Institution of Naval Architects in Genoa, on September 26, 1952. The authors are J. VENUS and E. C. B. CORLETT, naval architects for the Aluminum Development Association and the British Aluminum Company, respectively. The article, published in the October 1952 issue of "The British Motor Ship," describes tests carried out by the Aluminum Development Association in conjunction with the Ministry of Transport to determine the position regarding aluminum structures on passenger ships under the requirements of the 1948 International Conference on Safety of Life at Sea.

The 1948 International Conference on Safety of Life at Sea has now been ratified by the requisite number of member countries and will come into force in November. This Conference, which was attended by thirty countries, was held in London, and resulted in agreement on three alternative methods of fire protection. These three methods do not lend themselves to a single compromise and their origin can be clearly recognized. However, they are all based upon the establishment of major vertical zones by means of "A" class bulkheads.

Method I:—The construction of internal divisional bulkheading of "B" class divisions (as defined later), generally without the installation of a detection or sprinkler system in the accommodation and service spaces.

This is the system which was put forward by the United States, and is in fact the system adopted exclusively in American passenger vessels. Some recent installations abroad, for example in Italy, have adopted this practice.

Method II:—The fitting of an automatic sprinkler and fire alarm system in all spaces in which a fire might be expected generally with no restriction on the type of internal bulkheading in the spaces so protected. This system has been adopted generally in all British passenger vessels and also in those of a number of Continental countries.

Method III:—A system of subdivision within each main vertical zone using "A" and "B" class divisions distributed according to the importance, size and nature of the various compartments with an automatic fire detection system in all spaces in which a fire might be expected to originate and with restricted use of combustible and highly inflammable materials and furnishings, but generally without the installation of a sprinkler system.

This method is basically the type of fire protection adopted in French passenger vessels. The three methods described are quite different in principle and each method has been developed to suit particular national preferences. At the 1948 Conference statutory requirements were laid down defining "A" and "B" class fire-resisting divisions and a standard fire test was agreed to.

EFFECT OF THE REQUIREMENTS ON ALUMINUM SUPERSTRUCTURES

The Conference states that the "main structure, including decks and deckhouses, shall be of steel except where the Administration may sanction the use of other suitable material in special cases. It shall be divided into main vertical zones by 'A' class bulkheads, and further divided for similar bulkheads, forming the boundaries protecting spaces which provide vertical access, and the boundaries separating the accommodation spaces from the machinery, cargo, and service spaces and others."

The final act of Conference, based as it is upon steel construction, would appear to discourage the use of aluminum. The same Conference, however, in the regulations dealing with stability requirements after damage, has made it more probable that aluminum will be used for passenger ship structures, as the new requirement covering residual stability after flooding has meant, in fact, that in many cases the required stability standards are difficult to achieve without the use of either aluminum to reduce top weight, ballast to lower the center of gravity, or an increase in the beam of the vessel. The latter solution is not always acceptable as, besides possibly increasing the power necessary for propulsion, the increased beam means that the reduction in metacentric height is consequently more severe after flooding. If, then, it is the case, as the authors believe, that the use of aluminum is likely to increase for passenger superstructures, the question of adequate fire protection becomes extremely important. It is obvious that there are three primary conditions to be met by any system of fire protection in aluminum structures.

The first is that there must be no undue addition of weight as otherwise this would destroy one of the main reasons for using aluminum in the first instance.

The second is that the cost of providing such protection must be economically comparable with any other system in steel vessels.

The third, and the most important, is that the appropriate authorities—in the case of Great Britain the Ministry of Transport, Marine Safety Division—should be satisfied that any such method provides adequate safeguards, bearing in mind the lower melting point of the aluminum alloys, approximately 600 degrees C. (1100 degrees F.) compared with about 1400 degrees C. (2500 degrees F.) for steel.

VERTICAL AND HORIZONTAL ZONING

One of the primary requirements of the Conference is that accommodation must be divided into vertical zones and not more than 131 ft. in length and that these zones must be divided by bulkheads capable of resisting the passage of smoke, flame and heat for one hour.

The vertical propagation of the outbreak is prevented by the steel decks with their coverings. In steel ships this zoning is basically complete and requires only insulation of the "A" class bulkheads. However, in the aluminum structure, while the vertical zoning follows the same pattern as with steel, it is necessary to reconsider the case of horizontal zoning. Temperatures specified for the "Standard Fire Test" are such that unprotected aluminum is bound to melt and hence vertical propagation of flame is possible through collapse of the structure in the compartment in question. It is apparent that horizontal insulation under the deckhead is required, and this could conveniently replace the deckhead linings normally used in passenger accommodation.

While it is realized that the use of deckhead linings is not universal in all passenger spaces, accommodation in aluminum structures is likely to be of a high grade due to its location, and lined throughout. This, then, constitutes a special case and is the main point of difference between the necessary protection for steel and aluminum structures.

In addition, all control stations, such as radio rooms, all lift wells, boundary bulkheads, cargo spaces, machinery spaces, generator rooms, etc., are required to be of "A" class construction, and it does not seem that any difference in basic method is needed whatever the material of the structure. There is a positive requirement for stairways, however, and steel frame construction is obligatory for these even in aluminum structures. The efficient isolation of the staircase well would appear to be of great importance. The aim should be to prevent continuous convection currents by some means such as heavy fireproof curtains or self-closing "B" type swing doors.

PILLARS, DAVIT SUPPORTS AND BOAT EMBARKATION STATIONS

A separate problem both in steel and aluminum construction is set by pillars, davit supports, and by the fact that, in general, the structure should maintain its integrity in the region of the boat embarkation stations. In an unprotected steel structure actual melting is improbable, but it is evident that danger arises from two factors, i.e., severe distortion of the structure in general and local temperatures and smoke sufficient to make the vicinity untenable.

Presupposing a fire in a superstructure zone immediately below or adjacent to the boat embarkation stations, the zoning arrangements would prevent the actual spread of combustion. However, at a temperature of 927 degrees C. (1700 degrees F.) steel is a weak material with an ultimate strength of approximately 3.5 tons per sq. in., and has expanded by about 0.14 in. per foot of its length. Steel pillars retain little strength at these temperatures, and complete collapse of the structure is probably prevented by plating taking the imposed loadings as membrane stresses of a primarily tensile nature. Very severe distortion in the zone in question cannot but result, and efficient manning of the boat stations would be rendered problematical by these factors.

In the case of aluminum it has been shown earlier that protection is essential in order to prevent actual collapse of the structure, and the conclusion to be derived from the foregoing discussion on a steel structure is that, in fact, protection in these locations is likely to be essential for the retention of efficiency. Thus, from the viewpoint of the retention of function there is a good case for the adoption of Method I in the region of the boats and of stairways, etc., complemented by "A" class insulation of adjoining deckheads. This conclusion would hold irrespective of the basic structure of the material. It would seem further desirable that deckhouse boundaries should have a rating intermediate between "A" and "B" class in that they should resist the passage of smoke and flame but with no restriction on the temperature of the unexposed face.

In this connection it is of interest to note that sub-chapter M of the United States Coast Guard Regulations specifically mentions lifeboat embarkation stations but does not require any protection beyond the use of steel or an equivalent material in decks and boundaries to adjacent spaces. However, subchapter M does require the use of wire-inserted glass for all windows and side

scuttles opening from accommodations containing combustibles on to boat embarkation stations. This would appear to be a wise precaution, but is not specifically mentioned in the Conference requirements.

In the case of open structures, such as boat decks extending beyond houses, it should not be necessary to provide any insulation, whatever the basic constructional material, as should fire have spread from the major zones to these positions the situation will have been out of control for some time and the entire accommodation untenable.

The suggestion has been made on occasion that steel beams, stiffeners and pillars should be fitted in an aluminum structure to maintain structural integrity in the case of fire, but it is difficult to see any justification for this except, perhaps, in the case of pillars. If uninsulated deck beams were fitted they would not prevent severe distortion—as discussed earlier—while the aluminum plate would still suffer collapse through melting. Steel pillars, unless insulated, would be of little use. After insulating the composite structure complete integrity would result, but this identical result can be achieved with the same insulation in an all-aluminum structure.

For the main zones, then, the conclusion to be drawn is that with both steel and aluminum, "A" class vertical zoning should be complemented by "A" class horizontal deck zoning and by the similar insulation of steel pillars. This, it is clear, must apply to all aluminum horizontal zoning and, in the opinion of the authors, should apply to the horizontal zoning of the steel structure adjacent to boat embarkation stations as well as to the spaces required by the Conference.

The second part of this paper deals with the practical details of this subject and with an experimental program designed to explore both separately and in conjunction the appropriate methods for vertical and horizontal insulation.

MINOR BULKHEADS

The next point that arises is the wide difference in approach between Methods I and II in respect to the internal arrangements of each main zone. Method I emphasizes measures for preventing the spread of combustion from its source, while Method II places the emphasis upon its immediate extinction. Where complete "A" class boundaries exist it is clearly a matter of opinion which method is adopted and there are arguments for each.

With Method I, although there are no restrictions on the combustibles in a space, by the use of "B" class minor bulkheads, the fire remains in the original space until it is burnt out. In order to construct "B" class bulkheads it is desirable to use a material which is entirely non-combustible and has a low thermal conductivity.

The most commonly used material is a form of asbestos board which may be unfaced, or faced with very thin wood veneers for use in spaces where a particular decorative effect is desired, or of lower density and faced with thin aluminum to produce a light-weight material. This type of material, however, is rather more expensive than the plywood commonly used in Method II and varies in weight, relative to plywood, from rather lighter with the light material to slightly heavier with the unfaced material.

A factor which affects the use of this type of material is the reluctance sometimes encountered to depart from the time-honored materials and their working. This should be a factor of relative unimportance and in its absence joinery working costs are not increased. The whole joinery outfit, however, is appreciably more expensive than if ply-

wood is used as in Method II, but, on the other hand, it seems likely that the absence of a sprinkler system at least counterbalances the increase. This conclusion is supported by such costing data as are available to date in Great Britain.

The choice then between Methods I and II appears to be fairly open for the steel structure, subject, in the authors' opinion, to the desirability of protecting the enclosed structure in the vicinity of boat stations. Conceding this, the extension of Method I to the entire structure might prove economically advantageous as opposed to any combination of the two methods.

With an aluminum structure, however, the preferred method is rather more obvious. It should be obligatory to insulate the deckheads with either sprayed asbestos associated with the normal deckhead lining, or better, with an asbestos composition board. If, in addition, it should be necessary to install a complete sprinkler system, the cost of protecting the aluminum structure would be appreciably in excess of the cost for a similar steel structure. By the use of Method I and the avoidance of the sprinkler system, the aluminum structure would incur no significant disadvantage in weight or cost.

SPRINKLER SYSTEMS

As this method of fire protection is adopted in the majority of modern vessels it is appropriate at this stage to consider the reasons for its widespread use. In the first place, it is a most efficient method of preventing fires as has been proved by experience on many passenger vessels. The use of sprinklers places no restrictions on decorative materials and cabin partitions and this is particularly attractive to the shipbuilding industry.

On the other side of the balance sheet are the not inconsiderable cost of the installation and the risk during building and repair when the system may not be in operation. It is common practice, however, to install sprinklers deck by deck as the work proceeds, thus affording a considerable measure of protection. Nevertheless, it is significant that Great Britain, with its excellent record so far as fires at sea are concerned, does not show up nearly so well when fires in port or during building or repair are considered. This would seem to indicate that efficient manning of the vessel is particularly necessary at all times to ensure that the sprinklers are ready for operation and that when in port, or when building, a pump is available to supply the sprinklers when the headers are exhausted.

INSULATING MATERIALS

The materials used for this purpose must possess a number of features to be widely applicable. In general these may be summarized as follows:—

(i) Low conductivity.
(ii) Good strength.
(iii) Reasonable weight.
(iv) Reasonable cost.
(v) Easily installed.
(vi) Non-hygroscopic.
(vii) Of good appearance.

Commenting on these features, (i) is fundamental while (ii) is self-evident if the material is to supply its own support between attachments to the structure. Moderate weight is important as a significant increase relative to plywood would constitute an overwhelming disadvantage.

There does not appear to be a necessity for great resistance to thermal shock as should a fire hose be directed

into, say, a cabin with "B" class boundaries, the material will have fulfilled its purpose in restricting the conflagration and allowing the fire-fighting party to approach the seat of the fire.

There are several suitable types of material, mainly based upon mineral wool or asbestos fiber. Mineral wool matting or asbestos may be attached to the surface in question or the asbestos may be sprayed onto the surface or compressed into board form. This board may be compressed so as to be self-sufficient or it may be faced with steel or aluminum sheets. Alternatively, a thinner sheet of asbestos cement may be metal faced.

Sprayed asbestos has been used for a considerable time and offers excellent insulation. Owing to the moisture-absorbing properties of this material it has found widespread use for the prevention of condensation, but this is by no means an advantage where weight is important. The weight and cost of the combination of sprayed asbestos and plywood is an unacceptable disadvantage if used, for example, to insulate all the horizontal zoning material of an aluminum structure. The properties of the material are given in Table 1.

Asbestos composition board is handled in the same way as plywood and has acceptable mechanical properties. These properties are adequate for the construction of free standing minor bulkheads but, of course, the panels require joining to one another and light steel pressed sections are normally used for this purpose. The sections must have adequate expansion gaps at the ends as at 1700 degrees F. (927 degrees C.) a 7 ft. 6 in. length of steel has expanded by 0.90 in., and if restrained, a sideways deflection of some 3 in. would result.

A lightweight version of this material is faced on both sides with thin aluminum 0.025 in. sheet. This protects the less dense asbestos composition and, as was shown in the "Nantasket" test, resists standard test conditions adequately. Other materials used are based on slag wool or a combination of asbestos cement and sheet steel. Examples of both of these have received approval for "A" class steel bulkheads. The "A" class materials listed in Table 1 give suitable thicknesses when both sides of the metal bulkhead are insulated.

TABLE 1.—INSULATING MATERIALS

Material	Thickness	Weight: lb per sq. ft.	Use and Classification
Plywood	¼ in.	1.50	Not an insulator.
Plywood	⅜ in.	2.60	Not an insulator.
Asbestos-composition board (standard)	½ in.	3.2*	*B*-class free-standing bulkhead.
Asbestos-composition board (standard)	¼ in.	1.55* to 1.70†	*A*-class bulkhead and deckhead lining.
Asbestos-composition board (light weight) aluminum-faced	½ in.	2.40‡	*B*-class free standing bulkhead.
Sprayed asbestos	0.79 in.	1.0§	*A*-class bulkheading.
Slag wool	1 in.	1.3	*A*-class bulkheading.
Asbestos cement and steel sheet	¼ in.	4.5	*A*-class bulkheading.

* Actually measured by authors.
† Samples from two different manufacturers.
‡ Data obatained from the U.S.A.
§ This value is for dry material and may be exceeded in humid conditions.

CABIN BURN-OUT TEST

The test program was planned by the authors with the advice and assistance of the Ministry of Transport.

Although the results of the bulkhead and deck tests were satisfactory, it was felt that further confirmation of the suitability of Method I insulation for aluminum structures should be sought. It appeared that this experiment should take the form of a full-scale test on an aluminum structure designed to represent part of an aluminum deckhouse.

The object of the Cabin Burn-out Test at present described was mainly to assess the protection afforded by insulation to aluminum structures in an actual fire, and to ascertain how these results were related to the Standard Fire Test results when there was no restriction on the amount of combustible material in the cabin. In particular, details such as ships' side scuttles are not covered by the statutory tests and their inclusion in the Cabin Burn-out Test was intended to give data on their performance under the conditions of a serious fire.

For reasons of economy, the size of the structure was limited to 12 ft. by 12 ft. by 8 ft., and it was constructed entirely in NP5/6 and NE6 using riveted construction. The main test cabin was a two-berth room of 80 sq. ft. over-all floor area and adjacent to it there was part of another cabin with the test cabin opening on to a corridor inside the main structure. The contents of the cabin provided as much combustible material as is ever likely to be encountered in a room of this size, all furniture being painted wood and foam rubber mattresses being fitted to the bunks. Table 2 gives particulars of the deck

TABLE 2

Bulkhead or deck location	Protection	Openings	Fixing of insulation
Bulkhead (A), ship's side	½ in. asbestos board	2 10-in. diameter aluminum ports	Screwed to 1 in. grounds on face of 6 in. × 3 in. channel stiffeners
Bulkhead (B), deckhouse end	½ in. asbestos board	1 10-in. diameter aluminum port Door to corridor	Screwed to 1 in. grounds on aluminum bulkhead plating
Bulkhead (C), casing side	½ in. asbestos board	None	As above
Bulkhead (D), deckhouse end	Unprotected	Door to adjacent cabin and corridor	
Bulkhead (E), long corridor partition, bulkhead free standing	One panel ½ in. asbestos composition board. Wood veneered. Two panels aluminum faced asbestos composition board ¾ in.	One door 6 ft. 6 in. × 2 ft. 0 in. left open. Door ¾ in. asbestos composition board	Bulkheads ¾ in. overall thickness located in aluminum channel screwed to deck and screwed to aluminum angle at deckhead. Aluminum sections protected by skirtings.
Bulkhead (F)	Three different panels. Two as above and 1 × ¾ in. asbestos composition board unfaced	None	As for bulkhead (E)
Roof (G)	½ in. asbestos board	1 8-in. square vent opening trunked through deck	As for bulkhead (A)
Floor (H)	The aluminum deck plates in the cabin were covered with 5/16 in. thick sand filled Latex cement underlay on which was laid ¼ in. thick thermoplastic resin bonded tiles.		

and bulkhead insulation, together with notes on the methods employed for fastening. Three side scuttles were fitted, these being of 10-in. nominal diameter cast in aluminum alloy LM-6. Two of these were fitted with ordinary plate-glass and one with armor-glass. This latter was used as an observation port during the experiment. A further observation port with a mica insert was used situated in the center of the adjacent cabin bulkhead. The frames of the side scuttles were uninsulated, the asbestos composition board insulation being trunked to form a square surrounding the scuttle. A panel of board was attached direct to the bulkhead plating, so that none of the latter was directly exposed to the fire.

For the test one of the three side scuttles was left open, this being the one immediately above the desk, and also the corridor door was ajar. There was also an open 8-in. square vent in the deck-head, the object being to ensure a sufficient supply of oxygen to support combustion. This vent was trunked with asbestos composition board, the trunk having a clearance of 1 in. all round from the aluminum deck plating.

DESCRIPTION OF TEST

The test was carried out on a fine sunny day with a light wind blowing along the cabin corridor, the cabin being erected in the open. The fire was lit by dropping a lighted torch into a waste-paper basket; it grew slowly but, within 10 minutes was intense and there were several subdued explosions in the room.

The unexposed face veneers on the center panel of bulkhead F were smoking at 15 minutes, and suddenly the panel, and with it the bulkhead collapsed. Flames issued from the open door and the recording station near this point had to be evacuated, as, although the personnel were protected by asbestos boards, the flames reached out round the barrier—a distance of about 8-9 ft. from the fire.

The intensity of the fire diminished rapidly after 25 minutes from lighting, and it could be seen that the whole of the combustible material left in the cabin was then burning at floor level. Three of the thermocouples recording air temperatures ceased functioning at about 30 minutes and one of the ceiling panels fell at 35 minutes. After 25 minutes the two glass frames on the closed side scuttles fell away. At this stage it was obvious that the fire was dying out.

Although, where possible, recordings were continued for a full hour, the only temperatures that were not falling were those of the floor, due to smouldering embers lying on the surface.

CONCLUSIONS FROM THE CABIN BURN-OUT TEST

The test showed that aluminum structures can be protected efficiently against the most serious shipboard fires. It also showed that a normal deck covering affords sufficient barrier to the downward passage of heat.

The distortion in the aluminum structure when protected in this way is practically negligible. The test proved that it is possible to get an intense conflagration giving temperatures materially in excess of the Standard Fire Test.

The test also showed that aluminum side scuttles, when closed, afford considerable and sufficient protection and only fail well after the peak of a fire in such a space has passed.

To sum up, it is the opinion of the authors that this test proves conclusively that aluminum structures can be rendered completely safe, while, in general, the normal arrangements for "B" class partitioning should be adhered to.

The authors take complete responsi-

bility for the opinions expressed in the paper and for the conclusions reached, which are:—

(1) That Method I fire protection is, for economic reasons, the preferable type of fire protection for aluminum superstructure in passenger ships.

(2) That several suitable insulating materials exist, but those considered to be most suitable are of the asbestos composition board type.

(3) That this type of fire protection need not result in increased weight over Method II and, in the absence of sprinklers, should not differ greatly in cost.

(4) That the incorporation of steel members into an aluminum structure, while introducing subsidiary disadvantages, would not appear to afford additional protection.

(5) That in a ship insulated by Method I all pillars should receive protection whether the material be of aluminum or steel.

(6) That windows and side scuttles opening on to boat embarkation or boat loading stations could, with advantage, be fitted with flameproof glass and that adjacent bulkheads and decks should be to a modified "A" class standard, unless the decks be merely overhanging decks with open spaces below.

(7) That particular attention should be paid to fixing arrangements for insulation and that adequate expansion allowances are essential when metal grounds are used.

(8) That the normal types of deck covering effectively prevent the downward transmission of heat when laid over aluminum plating.

(9) That a fire which breaks out in a cabin of the type tested but with standard "B" class divisions will burn itself out without spreading the fire, even if it is never detected. If fire hoses should be directed on to the hot asbestos board the insulation may shatter. However, this presupposes close approach to the seat of the fire and thus vindicates the protection afforded.

CAPTAIN O'SHAUGNESSY— BUSINESS MAN IN BLUE
Cost Consciousness in the Fleet

COMMANDER JOHN A. HACK, U. S. NAVY

THE AUTHOR

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Captain Michael O'Shaugnessy United States Navy, was indeed a paradox! By nature extremely frugal, undeniably capable in his profession, for the past six months he had been managing a two million dollar a year business enterprise without completely being aware of the magnitude of his position.

Throughout his twenty-five years of service, the present Commanding Officer of the U.S.S. *White Mountains* had been an outstanding officer. Good fortune coupled with astute professional planning had allowed him to serve in capacities which had given him broad naval experience. The operational capabilities and limitations of various types of ships; the complexities of Staff work at the Force and the Fleet levels; even the magnitude of the problems confronting the Bureaus and Offices of the Navy Department were well within his scope of knowledge. Diversified experience, coupled with natural capabilities and continuous personal study, had well qualified O'Shaugnessy to be a potential naval leader. He was top drawer material!

In a more personal way, O'Shaugnessy's financial sagacity had made him the envy of many a classmate. Years ago he had begun to put a small part of his income away for that inevitable rainy day to come. Life had been kind to him and to his family, so that his small investments made through the years now showed quite tangibly. Last year he had noisily celebrated "the burning of the mortgage" on a lovely Coronado home. His son was in the second year of college, with his tuition being paid painlessly by an educational insurance policy taken out when young Mike was an infant. Small investments

in government bonds, in stocks, and insurances were now augmenting his income in the form of regular dividends. Not that he was rich by any worldly standards. He was rather "well situated." Yes, O'Shaugnessy was an outstanding man. Capable of being a success in many fields of endeavor, he most certainly was in his chosen one. But he had one chink in his armor. This is the story of that one flaw and the effect it had on O'Shaugnessy and his two million dollar business.

Shortly after he had taken command of the *White Mountains* his young Repair Officer, a Management Engineer, had discussed the principles of production planning and control necessary in any repair activity, but specifically in the ship's Repair Department.* Patiently, with the Captain's avid cooperation, and the thorough training techniques of the Repair Officer, the personnel of the *White Mountains* had developed a planning, scheduling, and control system which, while not the envy of the General Motors Corporation, had none the less helped to increase the productivity of the ship. Conservative estimates, based upon production records, indicated that with the same equipment and manpower, the ability of the ship to perform repairs had increased by twenty-five per cent.

About this time O'Shaughnessy began to read about Cost Consciousness. One article warned that the United States was becoming more and more dependent upon overseas sources for her raw materials. No longer was it possible just to get an appropriation for money to spend on new construction and repairs, then automatically to buy the finished product. The allocations of scarce materials were being felt by everyone. Even on the *White Mountains*, materials were becoming scarce. Stainless steel, copper tubing, electrical and electronic equipment . . . all were on order, but that hadn't filled the storerooms. Letters directing him to be cost conscious flowed across his desk from Bureaus, Offices, Force and Type Commanders. All spoke of the necessity for the conservation of funds. Only in the gravest of emergencies could quarterly maintenance funds be augmented. Each letter spoke in general terms concerning the conservation of manpower. Each was most explicit concerning materials, and in the urgency of strict supervision of the quarterly maintenance allotment. It wasn't long until each officer and man on the ship had gotten the word. The Repair Department melted down scrap which could be used again and was able to save in monies previously spent for metal billets in the foundry. Copper wire; old lockers; broken bits of machinery; steel shavings . . . each found its way to a salvage activity and helped to delay that inevitable day when the United States might become a have-not nation in its mineral resources. O'Shaugnessy skillfully and forcefully directed and controlled the expenditure of the $16,000 entrusted to him every three months for the maintenance of his ship.

Browsing through some reports from a friend in Washington, he read that out of a $90 billion budget last year the military had been allotted $57 billion. In the present fiscal year they had been given $47 billion out of a total of $60 billion. The sums were beyond his comprehension. However, he could understand that he and his associates would be spending sixty per cent of every tax collected. Economy was vital to the national security! He read one other interesting item . . . interesting in that it was the direct impetus which launched O'Shaugnessy into the sea of true cost consciousness. The House of Represent-

*(See "Management By Exception"—JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC. —Nov. 1951).

atives had hired a staff of twenty lawyers, accountants, engineers and economists, plus FBI agents, to take the Federal Budget as it comes from the President and find the soft spots. They were also to make year round studies to search out wastes, extravagances, and inefficiencies throughout the Federal agencies and departments.

Very proud of his success in the material conservation program, confident in his abilities, anxious to show off his modern Repair Department, O'Shaugnessy imagined to himself the feather in his cap which would result from the visit of such a group to the *White Mountains.* He called in Lieutenant Commander Jones, that same Management Engineer who had educated him in the philosophies of production planning and control, with the sole purpose of bragging a bit. "If all ships and repair activities were run like this one, we wouldn't be spending so much money!"

But Lieutenant Commander Jones did not long share either his confidence or his enthusiasm. "Captain," he brashly cut into what had been a very self-satisfying monologue on the efficiencies of the *White Mountains,* "do you realize that you are spending almost two million dollars a year to run this ship? Sure, we're on the right track. We *have* saved a little money. But we have a long hard row to hoe before we can start bragging to others about it."

Jones excused himself just long enough to get to his cabin and back. He carefully laid a piece of paper in front of the Captain, "Here, sir, are the real costs of running the *White Mountains* for one quarter, unvarnished and unhidden!"

O'Shaugnessy glanced at the sheet and read:

U.S.S. *White Mountains*

Jan-Mar 195x

COSTS OF OPERATIONS

LABOR		
Pay and Allowances		
Officers	$ 40,801	
Men	$248,491	
General Mess		
Men	$ 65,710	
Total Labor Costs		$355,002
MATERIALS		
Ship's Allotment	$ 16,000	
Repairs to other Vessels	$ 56,615	
Total Material Costs		$ 71,615
TOTAL COSTS (Fuel excepted)		$426,617

"As you can see Captain," Jones started, "we actually spent almost half a million dollars last quarter, but we were only emphasizing the importance of a very small percentage of it. Why our food bill alone was almost as great as all material costs combined, but I seriously doubt that either of us gave five minutes' thought to the fact that garbage may be as expensive as wasted materials.

NECESSITY FOR STANDARD COSTS

"Notice that costs are the sum total of an expenditure of manpower over a definite period of time and the expenditure of materials. This being so, in any analysis of the management of the *White Mountains* we must establish a capacity to do work, derived from our manpower in units of time, as well as a true cost of materials which should be used in the performance of that work. These, when expressed in dollars, are actual standards of costs from which we can determine our performance. Let's look at a simple example. A destroyer requests us to manufacture a length of pipe. The work should be completed by the expenditure of twenty man hours of labor and with five dollars' worth of sheet steel. The standard cost for that job, assuming that no other expenses were present, would be the cost of the labor added to the cost of the material. If we actually expended thirty man hours and used ten dollars' worth of material, then the work has not been done efficiently. We obviously lose, to the taxpayers' detriment, the difference between actual and standard performance. At the shop level we would attempt to take corrective action to remedy an obvious waste of funds. It is equally important that at the ship level we establish standards from which we may measure our cost performance, and through analysis of every deviation from standard seek to prevent unnecessary costs from recurring. We can in fact be forewarned as the year progresses, whether we are creating a profit or a loss in our operations. Without complexity, we can, if we desire to, establish standards. Without them to use as a measure of success, we manage aimlessly and blindly, and certainly without the ability to justify our expenditures.

ESTABLISHING A STANDARD CAPACITY

"There is little information in official documents as to the capacity of a destroyer tender to do work. Obviously its capacity originates in each shop and is the sum total of the capacities of those shops, expressed in man hours, machine hours, or some measurable unit. Although we have set our own capacities in each shop, as a standard from which to plan and then to control production, our standards may be higher or lower than those set by other activities. Of itself, this need not worry us, since competition and performance figures will tend to create accurate performance standards.

"At the ship level it would be inconvenient to use manhours as a unit of measurement. We are interested in the broad picture of our performance in terms of the product we sell, that is destroyer repairs. How many destroyers should the sum total of individual shops be able to repair in any given period? Here again there is little official information. The first reaction of most naval officers is the same as it is to production planning. The problem has so many variables that no standard may be set. Yet a pamphlet "Bin Loading of Ordnance Spares Aboard Destroyer Tenders" (prepared by the Bureau of Ordnance Stock Officer, Planning Division, Washington, D. C., on June 25, 1951), courageously states 'The average demand upon a destroyer tender is calculated upon support of 19 DD types during a six-month period.' Bin loading of spare parts is based upon a tender's support of 38 DD's.

"During the past year we actually overhauled during regular availabilities or their equivalents, 52 DD types. Certainly our past performance is as good

a criterion to start with as the Bureau of Ordnance assumption. Lastly our production records of the last six months indicate that we consistently utilize our maximum capacity to do work, only when four destroyers are alongside for availability for a two-week period. In this connection it is important to remember that every three months the tender requires two weeks of uninterrupted upkeep of itself to operate at this level. Under these conditions some shops have more work requested than they can accomplish, but on the average it represents our optimum productive status. Based upon experience, as verified from our records, we have a capacity to overhaul 88 destroyers a year. This is our best estimate of the standard productive capacity. We should use it as such for management decisions. The mere fact that there is such a wide discrepancy between the initial Bureau assumption, our actual performance, and our estimate of the standard based upon experience, is indication enough that serious study of the Standard Capacity of Repair ships to do work is in order. The importance of this wide discrepancy we can better appreciate when we analyze the costs of idle capacity.

STANDARD COSTS

"You and I have been as conscientious in the matter of costs on this ship as any officer I have talked to. Yet unwittingly we have almost forgotten the forest of costs for one of the individual trees. We have talked, lectured, cajoled and threatened about the necessity of saving materials, in terms of the ship's quarterly allotment. What of the other costs? How much were they? What should they have been? Were they necessary? Were they within our control to do anything about? Here in detail are our actual costs, itemized on an annual basis."

Jones handed a second sheet of paper to O'Shaugnessy:

U.S.S. *White Mountains*

ANNUAL COSTS OF OPERATIONS

ITEM	AMOUNT	% OF TOTAL
MANAGEMENT		
Officers' Pay	$ 163,204	9.5
LABOR		
Repair Dept. Pay	298,189	17.4
Repair Dept. Food	78,852	4.6
Other Dept. Pay	695,775	40.6
Other Dept. Food	183,988	10.7
MATERIALS		
Ship's Quarterly Maintenance	64,000	3.8
Used in Repair of DD's	226,460	13.2
TOTAL	$1,710,468	100.0

"Does it surprise you to see that we have been expending most of our energies on the control of only 3.8% of our total expenditures? Or that only 35.8% of our costs go into the repair of destroyers? Our food bill alone is almost as great as our bill for materials! I'm sure that if either of us were asked what each item should be, as a standard cost, we would be at a loss for words! But we can establish standards if we really want to. Let's analyze each item as well as the sum total.

THE COST OF IDLE CAPACITY

"Assuming that all costs were reasonable and justified, we spent a total of $1,710,468 to overhaul fifty-two destroyers. Each one cost the people of the United States $32,893. Did they get a bargain? Well that depends upon which standards you care to take. All of the expenditures of the year can be expressed in fixed costs (those which we would have had to pay whether we overhauled one destroyer or a hundred) and one variable cost, the material expended in the repairs. That variable amounted to $226,460 for fifty-two destroyers, or an average of $4,355 per destroyer. How much should it have cost for each ship, considering both fixed and variable costs? Here are some indications:

	By BUORD Standards (38 DD)	*By Actual Performance (52 DD)*	*Optimum Capacity (88 DD)*
Fixed	43,647	28,538	16,613
Variable	4,355	4,355	4,355
Total	48,002	32,893	20,968

If we are to take the original Bureau of Ordnance assumption as our standard for planning then we made a handsome profit of almost $16,000 per ship, for we actually accomplished more work than we had been thought capable of. However, by more realistic standards, since the capacity we know we have was not used, someone caused a loss of $12,000 per ship in idle capacity. More simply, we spent considerable sums of money without any productive work to show for it. Some waste along this line is inevitable, but *planned* waste is not readily justified. The type commander could minimize the costs of destroyer overhauls by scheduling availabilities to our maximum standard capacity, by making provisions for scheduling ships of other types to use that capacity which he cannot employ, or by so streamlining procedures that we on our own initiative could accept work from other ships whenever we had the capacity to do so, without the formal approval of higher authority.

"The cost of idle capacity isn't too often appreciated by the military man, since he does not directly pay for the fixed costs of operations. It is with us none the less and accounts for very large sums of money. When capacity is idle through lack of proper planning, that cost is serious waste of one of our most critical national resources—manpower! The accumulated effects of this waste can often make it appear that more facilities and more manpower are needed, when actually the opposite is true. The fact that this cost is disguised, that it doesn't show in formal reports, and like the beginnings of a cancer passes unnoticed, makes it one of the most insidious wastes which we can encounter. Only by universal adoption of flexible budgets, based upon standard costs for various levels of performance, can the cost of idle capacity be analyzed and checked.

MANAGEMENT COSTS

"Management costs are the pay and the allowances of the officers attached. These are the costs of special naval skills and management abilities. If they are directed to the mission of the organization, directly or even indirectly, then they are well incurred. If, however, they are related to non-essential duties which contribute nothing to the repair activity or the welfare of the personnel, such costs can be a waste. The most important responsibility of officers, if they are not being wasteful of money entrusted to them, is to attempt with every skill available to them to achieve standard performance levels. For, if management does not . . . who will?

LABOR COSTS

"Labor costs, amounting to over 73% of our total expenditures, are important not only because they are the greatest, but also because they represent a cost of a national resource which is growing more and more critical to our national economy. Manpower has become such an important factor that the utilization of it is coming under the immediate scrutiny of Congress. Personnel in non-productive jobs should be reduced to a minimum. The corollary—the maximum which can be employed should be assigned to production jobs within the Repair Department. Only by so doing will we be reducing fixed costs incurred by departments which add nothing to actual production, while increasing productivity.

"Few naval officers, in the course of their normal duties, are ever required to study their responsibilities and throughout the entire area of their jurisdiction arrange a hierarchy of jobs into an organization through which they will execute the policies established by them or their superiors. The normal, even by those engaged in the preparation of standard organizations, is to *START* with the number of men allocated and build the job structure upon that. In effect we have a tendency to hire the men before we determine what the jobs are. Captain, would it surprise you to know that there are almost 350 men assigned to the deck department of the *White Mountains,* and that a job analysis indicates that there are only two hundred jobs to be done, even considering leave policies, sickness, and military requirements? Too many times we assume that since we have an allowance of men, that there must be a job for every one of them. How many jobs do we really have? When we determine that, and only then, can we allocate personnel intelligently, and, if appropriate, recommend proper allowances to the Bureau of Naval Personnel. That having been done planning, scheduling and control procedures must be employed if we are to accomplish our work in the one best way, with the most economical employment of manpower. These are but methods of establishing the proper standards and scheduling performance to those standards.

MATERIAL COSTS

"These, while only 17% of the total, are important to a degree unmatched by any other factor. Waste of materials represents a loss of money. More serious is that it results in a loss of resources which can never be replaced. The United States no longer has unlimited supplies of minerals within her boundaries. The steel ore deposits of Mesabi have been so depleted that we are already reaching out to Labrador and Venezuela for ore to feed into the furnaces of the steel

industry. Copper, oil, aluminum, coal . . . once removed from the earth can never be replaced therein. Excessive material use only accelerates the passage of time to that inevitable day when we must look elsewhere for our vital supplies. Do we waste material? Every day I believe that both of us see some evidence of it. To some extent we encourage it. Painting over areas which are still serviceable, and could get by with but a cleaning. Excessive emphasis on beauty as opposed to utility. Replacement of serviceable parts which *might* cause trouble, but again which *might* not. Lack of preventive maintenance of the type which every American has acquired as habit in the care of his automobile. Throwing metal over the side instead of retaining it for a shore salvage activity. The ordering of more parts than we need, because "they might be hard to get." All of these practices cost money. Worse they result in waste of vital national resources!

"Faults in administration which allow duplication of ordering can be as wasteful as actual destruction of material. For example, in certain ShipAlts which are to be accomplished by Repair Activities afloat, tenders must order the equipment necessary to accomplish the alterations. Since a long period elapses between the ordering and the receipt of the material, we must *guess* which of the applicable ships will be assigned availability to us. Although it seems logical to assume that if a ShipAlt is applicable to twenty ships, only twenty sets of material need be ordered, in fact tenders duplicate each other through their "guesses." The Bureau of Ships could control the material allocation by designating one stockpiling activity on each coast, to order all of the material, and have it available for ready issue to any tender which required it.

"Lastly, if we truly want to conserve materials, in the same manner that a civilian factory has to if it is to stay in competition with other manufacturers, we must accept the necessity of a strict material planning and control system within our production programs. Each job requires only a standard amount of material. That amount should be scheduled and performance controlled in the same manner as we are accepting the necessity to control our man hour capacity.

SUMMARY

"The true philosophy of cost consciousness leads us to certain methods which if adopted will guide us along the road to economy. Certainly no businessman can afford to violate the principles if he expects to stay in business, let alone if he expects to distribute any profits to his shareholders. Standards must be set for the proper utilization of manpower, time and materials, for these are the elements which combined result in costs. Having set such standards, at every level, we must not only use them to assist us in our management decisions, but through analysis of each element of cost, constantly strive to eliminate those which are unnecessary, and thereby set new standards. Economy, like success, is not achieved by accepting the status quo. True cost consciousness comes only with the full realization that there is one best way to accomplish any operation with the most economical expenditure of time, materials and money."

Captain O'Shaugnessy had good reason to remember that conversation of six months ago. For it was on that day that he came to the full realization that he was not merely in command of the *White Mountains* . . . that was but a position of power which gave him the authority to give orders, make decisions and set policies. He was in addition the manager of a concern which had a sales

volume of almost two million dollars a year. Modern management skills and philosophies were as important as his other naval skills, if he was to spend wisely the money of the people of the United States.

Today, O'Shaugnessy *was* a businessman in blue! It hadn't been easy, nor were his goals completely reached. But the *White Mountains* was organized on a sound job structure with complete emphasis on production. To the limit of his ability personnel were assigned to the Repair Department, with only the minimum required in the service departments. In other words he had established realistic manpower standards in his ship. The production planning and control program had been expanded to include material control, through the technique of allowing automatic issue of only standard amounts of material on each job. Further augmentation of material could be gotten only by special request which necessitated the calling of managerial attention to such request. Material salvage programs were intensified. Within his ship, O'Shaugnessy knew how much his standard costs of operation should be and he was well on his way toward achieving them. Through his efforts, material wastes unwittingly caused in the ShipAlt program were eliminated by the Bureau of Ships, and the Type Commander had by scheduling other types for availability and by allowing destroyers to have direct contact with the tender for all ship-to-shop work allowed full utilization of the tender's capacity to do work to the maximum extent possible. The *White Mountains* was effectively paying a quarterly dividend to every man, woman and child in the country in reduced expenditures. Equally important she was more ready to perform her wartime role with increased vigor, for wars are won too by striving for the objective with the greatest economy of forces and resources.

O'Shaugnessy neither received nor expected any medals. The satisfaction that he was spending his portion of that 60% of the taxes wisely was reward enough. He had no illusions that naval life would be revolutionized because of his activities. But others would follow in his path . . . and did! A leader who combined command powers with the philosophies and skills of the modern manager, he was still top drawer material. For the first time in his career he was a Business Man in Blue!

There are many O'Shaugnessy's in the Fleet. You see them every day without being aware of the fact. Some are Ensigns, some are Admirals. Because of them the Navy is, as it always has been and will be, just a bit better profession in which to serve. Are you an O'Shaugnessy?

RESISTANCE OF WATER TO SHIPS' MOTION

ACKNOWLEDGMENT

This article appeared in the May 1952 issue of the Russian magazine "Morskoi Flot," and its author is A. KARPOW. It contains an account of Soviet claims of the contributions of Russian scientists to the field of ships' resistance. The article was translated from the original Russian by E. C. MAGDEBURGER.

Development of ships' theory and, particularly of the part of it devoted to resistance of the water to ships' motion, began two centuries ago in Russia. Its birth was simultaneous with the titanic efforts in shipbuilding initiated by Peter the Great.

Success in the war with Sweden resulted in the acquisition of the Baltic coast line. A new capital of the nation was established with a direct outlet to the sea and a new waterway was built connecting the river Volga with the Baltic. The country was then faced with the problem of creating an extensive fleet. The development of shipbuilding was furthered by the establishment of the Admiralty in St. Petersburg, to build ships and have custody of the equipment and the experienced men for that purpose, and of the Russian Academy of Sciences.

At the end of Peter's reign in 1725, the Russian Navy consisted of forty-eight ships of the line. The practical needs of shipbuilding and navigation produced many theoretical problems connected with ships' design, their strength and seakeeping qualities, for science to solve. An enthusiastic supporter of Peter's work in shipbuilding and navigation was the first Russian academician and scientist, M. V. Lomonossov, who wrote of Russian commerce reaching India, China and Japan as well as the west coast of America. An outstanding event in the development of shipbuilding science was the publication in St. Petersburg in 1749 by L. Euler (1), of his basic contribution to naval architecture, called "Nautical Science," which according to A. N. Krilov, was the first scientific work in the world devoted to the systematic analysis of the seagoing qualities of ships. This book deals among other problems with the theory of water resistance. While appreciating Euler's work as a pioneer of the theory of resistance to ships' motion (in modern times this is being based on different scientific positions) it is necessary to

keep in mind that he became one of the founders of theoretical hydrodynamics, a science serving as a basis of the modern theory of resistance to motion. Formulas developed by Euler and bearing his name serve as the basis of almost all subsequent theoretical investigations in hydrodynamics. To the works of Euler concerning ships motion belong "An Experiment of a Theory of Friction in Liquids" and "Complete Review of Problems in Building and Navigating Ships."

Contemporary with Euler in the St. Petersburg Academy of Sciences, 1726-1733, was Daniel Bernoulli, who gave the world the famous formula which serves as the basis of all engineering calculations concerned with the movement of liquids (*2*).

Several decades after the works of Euler and Bernoulli, foreign scientists attempted to solve the problem of resistance to the movement of ships experimentally (d'Alambest in 1775-1777; Beaufoy in 1791-1798). These attempts show how important was their work to the practical needs of the developing shipbuilding industry. These first efforts were not successful. More successful results were achieved in the next century by the Russian scientists Professor S. A. Burachek, M. M. Okounev, I. P. Alimov and some others. For their time the theories of these scientists were progressive and of higher level than the work of foreign investigators.

The famous Russian scientist, D. I. Mendeleev, showed much interest in the development of shipbuilding and to the questions of resistance to ship movement throughout his scientific career. He was the author of such publications as "On Resistance of Liquids," "Results of Experiments to Determine Frictional Resistance of Water to a Uniformly Moving Cylindrical Surface," and "Iron Shipbuilding in the South of Russia."

In the foreword of his 1880 work, published as a book, Mendeleev wrote: "Beginning the study of resistance, I confess that I did not expect to find such a scarcity of theory and experiments pertaining to it, as actually existed. One would suppose that in the application to shipbuilding and ship propulsion the question would be thoroughly covered. However, actually ships are being built by memory resulting from practice and experience and not by calculations based on theory and experimentally determined resistance." And later "Sea traffic itself should benefit greatly from new accurately made experimental determinations of resistance to motion, because they will result without a doubt in a more satisfactory theory of water resistance than now exists, as well as the possibility of reaching such targets in naval architecture as are demanded by practice, i.e., higher speeds with minimum fuel consumption and maximum displacement and with suitable stability, turning ability and other ship characteristics. If it is beyond my capabilities to further such important questions as mentioned above, I will at least make the road easier to later workers by assembling here all that I consider most important and pointing out means for experimental investigation, which in my opinion will further the question of resistance of surrounding medium beyond contemporary level."

In his published works devoted to the question of resistance of the surrounding medium Mendeleev gave a critical review of all materials existing at the time. The matter as it stood in the second half of the eighteenth century concerning the science of resistance of the surrounding medium was characterized by a deep rift between the theoretical methods of investigation and attempts to find a practical solution experimentally without recourse to theory.

Mendeleev showed conclusively the hopelessness and futility of either approach by itself. He gave a deeply sci-

entific explanation of the erroneous position of Newton, who as a typical representative of the first method, built his hypotheses on the resistance to the movement of solids in liquids by pure deduction without regard to experimental data, and these proved inadequate to the demands of practice. By these hypotheses Newton hurt the development of science and created stagnation by braking its forward movement. Discussing the causes of Newton's errors Mendeleev wrote: "It is also impossible to assume that such correct hypotheses could originate without the accurate knowledge of all facts or by means of only a general acquaintance with the phenomena. While such an accident is not impossible none was recorded by the history of knowledge. Small wonder therefore that in the complicated question of resistance of the medium, Newton and other theorists without the accurate knowledge of actualities assumed such hypotheses which do not satisfy the nature of the phenomena."

To a no less severe criticism Mendeleev subjected the representatives of the second method, of whom the English engineer Froude was the most prominent, he solved the problem of determining the value of the resistance to the movement of ships by means of model experiments. Having received large sums from the British Admiralty, Froude built a basin and conducted in it numerous tests of models geometrically similar to the actual ship. However the results of the tests conducted by Froude did not and could not give the desired values, because he did not attempt to get a scientifically based solution of the problem but only desired "to get from nature the figures needed by the British navy."

Mendeleev indicated the only correct, strictly scientific, materialistic road for science to develop, following which it was possible to arrive at the solution of problems: "a rational experiment is needed to solve the problems while the young and inexperienced mental activity can be led to either this or that side, until trained by experience to the right road it can drag behind itself or carry on itself all of the substance of experimental knowledge, as a horse trained to a bridle will carry its load where it should."

These observations of Mendeleev were several decades ahead of the ideas of the foreign scientists, propounded at the beginning of this century, and were later developed into the well-known theory of the "boundary layer of friction." As a practical result of the theoretical conceptions of Mendeleev on friction of liquids, a formula was produced to calculate simply and with great accuracy the value of resistance by friction for a flat surface while moving in water. Concerning this formula of Mendeleev professor A. P. Van der Fleet of the Polytechnic Institute of St. Petersburg wrote in his book "Theory of Ships" (1911): "The formula as offered by Mendeleev satisfies experimental results better than the one with the fractional power (proposed by Froude). The experimental results show that the force of friction does not vary with any power of speed but this power itself grows with the speed. At very slow speeds friction is almost proportional to the first power of speed and in Mendeleev's formula at low speeds the member with the square of the speed is insignificant, while with rising speed it becomes of greater significance."

It is not without interest to note that after 45 years the forgotten formula of Mendeleev turned up in Germany under the name of "Kempf formula." Kempf only made its coefficients insignificantly more accurate after experimenting with pipes and plates.

Mendeleev and Admiral Makarov supplied the initiative for the construction in 1894 of a basin for the testing of

ships' models. The first leaders of this basin were the outstanding shipbuilders A. N. Krilov and I. G. Bubnov. For many years this model basin was the center of concentration of theoretical and experimental investigations on the speed of ships.

Outstanding results of theoretical hydrodynamics toward the end of the last century permitted the solving of many problems connected with the motion of solid bodies in a liquid and adapting the results received to the calculation of resistance to the motion of ships.

Professor N. E. Joukovsky, discussing the problem of ships' motion in shallow water, produced in his article "On Shallow Waves" (1902) a theoretical solution for the value of resistance to motion with the resultant equation for the surface of minimum resistance. To him belongs also the investigation "On the Form of Ships," which solves the problem of optimum shape of ships' hulls. Simultaneously with the above articles by Joukovsky was published the work of the Australian scientist Mitchel (1898) on the wave resistance of ships in deep water. Unfortunately this interesting solution was not utilized by shipbuilders and in time was forgotten. Only a quarter century later the Soviet scientist G. E. Pavlenko found a way to utilize this solution for practical purposes. The solution of the problem of analytical calculations of wave resistance of ships' hulls in Pavlenko's formula permitted its calculation for ships of conventional form represented by a theoretical drawing or by a table or ordinates, and gave an opportunity to check it experimentally as was done on a large scale in the model basin at Leningrad. Developing further the theory of wave resistance Pavlenko obtained a solution of the problem of the form of ships' hulls, having for given dimensions and displacement a form with a minimum wave resistance at a desired speed.

A more perfect solution of the problem of wave resistance of a ship's hull belongs to the Soviet scientist, Professor L. N. Sretensky, who published in 1938 a brilliant generalization of the solutions by Joukovsky and Mitchel for any depth of water. Such significant success became only possible because of the successes of the Soviet school of the theory of wave motion of liquids headed by N. E. Kochin.

The ideas on the boundary layer of friction, developed in the beginning of the present century, permitted the creation of a new direction in the treatment of resistance to friction. These works changed our view of the physical meaning of the phenomena connected with resistance to friction and gave highly valuable results from the practical point of view, due mostly to the efforts of Soviet scientists L. G. Loitsinsky and K. K. Fedajevsky.

To our country belongs the honor of building in 1902, the first aerodynamic wind tunnel in the world. Such questions concerning the speed of the ship as for instance, the determination of the air resistance of the above-water structure of the ship, are experimentally obtained in these wind tunnels. The creator of the first wind tunnel was the great Russian scientist Joukovsky.

Our famous Russian scientist, A. N. Krilov, has often turned to the solution of the problems of resistance to ships' motion. He considered the question of formation of shallow water waves and studied known cases of reduced ship's speed in connection with decrease in depth of water, and computed and published the first tables in existence of values of coefficients of friction in the metric system of measurement. Under Krilov's supervision the model basin in 1904 conducted an exceedingly interesting series of model tests for the cruiser *Ascold* (3) with a variable ratio of breadth to depth. The material of these investigations is of interest up to the present time. Repeatedly Krilov

called attention to the effect of roughness of the outer surface of the ship's hull on the resistance due to friction and gave practical advice on its reduction.

Attention must be invited also to the following work completed before the Great October Socialist Revolution. In 1905 the engineer Afanasjev engaged in analyzing data from ships' trials hit upon a very gratifying formula for resistance which is used occasionally even to this day. In 1911 there were published two parts of a book by V. N. Karapetov "On Resistance to Motion of Ships on Inland Waterways" in which a formula was derived based on data by the Russian researcher Zviaginzev and other experimenters for ships resistance, which had a very wide acceptance in its time.

Russian researchers paid much attention to the effort of form of ships' hulls for inland waterways on the value of resistance to their motion. Priority on this question belongs to Professor I. G. Bubnov, who in 1906 developed an extensive program of investigation aimed at "determining the dimensions and power of towboats as well as dimensions and carrying-capacity of barges, in order to get the minimum cost of transportation and the most profitable use of capital investment" (S. V. Viahirev—Water Transport No. 2, 1923).

Among other questions listed in the program of tests it was intended to study the influence of the sharpness of the waterline and buttocks lines, of the length of the cylindrical insert, and of the relation of principal dimensions, on the resistance. It was proposed also to determine "if it was possible to achieve substantial improvement in existing types of river non-propelled vessels and if improvement is possible, then how these experiments should be made to get the most complete answer."

The results of these tests, successfully completed according to program and published by Viachirev in an article entitled "Research on Barges of Systematic Type," led to very valuable deductions. It was established that notwithstanding their modest speeds the non-propelled barges have a residual resistance forming a significant part of total resistance. Thus a suitable form of underwater body of these vessels can give considerable advantages. The French expert on the question of resistance of river ships De Mas, disagrees with this deduction and states that the resistance of river ships depends almost exclusively on friction and therefore it is useless to search for an optimum form of hull for this type of ship.

It was determined for the first time by these experiments that the shape of the buttocks has the most significant influence on the resistance of ships for the inland waterways. "The influence of the buttocks apparently predominates. A spoon-shaped model, although it has the disadvantage of blunt waterline entrance, nevertheless requires less towing force." This deduction overturned the convictions prevalent in those days and led to substantial changes in the form of hulls of ships.

Later on, during the Soviet regime, research on the optimum form of ships' hulls for inland waterways was continued by S. P. Muragin, Prof. V. V. Zwonkov, A. A. Kostukov and others, and led to those rather perfect forms of ships' hulls which are being used by our shipyards for the construction of river vessels.

When moving in limited channel depths a considerable reduction of the speed of the ship occurs. For a long time the question of the influence of depth on the magnitude of resistance remained little explored and the practical engineers could not calculate beforehand the loss of speed to be sus-

tained under any given depth of channel. The formulas recommended in foreign literature by Hebers, Sonne, and Gooche gave utterly unsatisfactory results. Not until 1936 did the Soviet scientists J. V. Hivs and U. V. Afanassiev come out with a sufficiently reliable method of calculation for the estimated reduction of the speed of the ship in shallow depths based on rational premises and giving results fully satisfactory to practice. Still larger attainments in the solution of this question are possible due to the theoretical investigations of Prof. L. N. Sretensky, who solved the problem of the magnitude of total resistance of ships when traversing canals or shallow depth channels.

The results of calculations made by Voitkunsky, Ovcharenko, Bolshakov and others using Sretensky formulas checked well the experimental data. Comparatively recently P. A. Apukhtin of the model basin of the Leningrad Shipbuilding Institute developed charts of speed reduction in shallow waters for high-speed vessels, which are very convenient to use.

For a long time there remained unstudied the theoretically very insistent question of ship's motion when gliding which permits the highest speeds in water transport. Investigations of Prof. G. E. Pavlenko and Prof. L. J. Sedov give very promising results of success to this question also.

Of great interest are the experimental data on the influence of scale effect when testing ships' models developed by U. V. Krivtzov and N. K. Ken. Of importance also is the work of Prof. V. V. Zwonkov and A. A. Kostukov "On the Influence of the Method for Making up the Tow on the Resistance to Motion" which led to the development of the numerical value of the so-called "tow coefficient" for the different methods of forming a tow for a given number of barges. These investigations were of great importance for the "Stakhanovzi" (men of highest efficiency) of water transport, helping them to hold the barges together that the total resistance of the combined tow is at a minimum.

Not a few interesting investigations were made by S. P. Muraguin on determining the influence of different forms of ships' hulls on resistance. In particular he is responsible for the comprehensive experimental investigation of resistance of various modifications of bow and stern ends of non-propelled barges and of the effect of variation of breadth to depth ratio on the resistance to ships' motion.

Special determination of hull resistance of fishing vessels and on selection of optimum form for them was carried out under the supervision of N. K. Ken and L. M. Nogid. Much work was done to create new methods of calculation of the approximate magnitude of resistance to motion of ships. Here the efforts of I. V. Girs, G. N. Kabachinsky, E. E. Pampel, P. A. Apukhtin and others deserve mentioning.

The last quarter of the century was characterized by a continuous national expansion of the efforts of the homeland scientists in the sphere of problems connected with resistance to the motion of ships. Thanks to the attention concentrated on the development of science and technology by our party and our government, our land has in its service a most remarkable cadre of scientific workers and a most perfect laboratory set up. This permits us to give the investigations in the sphere of hydrodynamics of ships, emphasis deserving of a country beginning to capitalize on the great works of communism. The creation of a mighty navy and the creation of the fleet serving the internal waterways are related to the building of giant dams and artificial lakes and canals emanating from the Volga, Dnieper, Don and Amu-Darja.

The fact that our ships possess excellent speeds is proof of unselfish service of our shipbuilders and scientists who combined structural perfection with seagoing qualities in our ships.

The Soviet government has valued highly the work in this sphere and has given Stalin's prizes for the successful development of methods of increasing the speed of ships to K. K. Fedajevsky, M. N. Veselovsky, A. N. Dobrovolsky, A. S. Perlmuttv and P. A. Epstein.

References

(1) From The Encyclopedia Britannica:

Euler, Leonhard (1707-1783) born in Basel, Switzerland, graduated University of Basel in 1723, studied geometry under Jean Bernoulli and became the friend of his son Daniel. In 1727, at the invitation of Catherine I he came to St. Petersburg as professor of physics and in 1730 succeeded Daniel Bernoulli in mathematics also. In 1741 went to Berlin, invited by Frederick the Great. Contributed many memoirs to St. Petersburg Academy and in 1766 returned to Russia where a cataract on his left eye left him almost blind. Died of apoplexy in 1783.

(2) From The Encyclopedia Britannica:

Daniel Bernoulli (1700-1782), younger son of Jean Bernoulli, professor of mathematics at the University of Basel. On return from St. Petersburg in 1733 he became professor of anatomy and botany at Basel and later of experimental and speculative philosophy. Most important work published is "Hydrodynamics" (1738), which proposed propulsion of vessels by reaction of water ejected from the stern.

(3) Built by Cramps in Philadelphia, Pa., U.S.A.

RESEARCH AND DEVELOPMENT FOR THE SECURITY OF AMERICA—A JOINT ENDEAVOR BETWEEN THE MILITARY AND THE CIVILIAN INSTITUTIONS

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Today in a nation not entirely sure of the future, we live in a period of struggle, of tension, of unavoidable crises and possible unexpected attacks. Throughout our illustrious history we have repeatedly been called upon, as an unready nation, to face desperate situations. Recent developments dictate that never again can we take this risk, lest we lose everything we hold worthwhile. We place, as we must, tremendous importance on the production of weapons to meet immediate crisis. For this we build huge factories, work shops and assembly lines. As we review the critical supplies necessary for national security we find there is one commodity of great need today which cannot be mass produced, and which is in scarce supply—*scientific knowledge and information.* It will be even more important for our survival as a nation in the future.

We would be less than realistic if we did not recognize the fact that World War II largely utilized to the utmost the storehouse of scientific knowledge and information then available. The development of new and revolutionary weapons needed to insure our future security depends upon acquiring new knowledge. It is possible to use substitutes for some of our metals and some hardware products but there is no satisfactory substitute for basic scientific advancement.

One of the most grievous mistakes this nation could possibly make would be to underestimate the capabilities of our enemies. We must not permit this in any field of endeavor, nor can we relax merely in the thought that our production lines are rolling, as this in itself may become a mental Maginot line. We must have new and better weapons. In this endeavor there can be no relaxation

of effort in our scientific research. America must maintain supremacy in scientific and technical information necessary for the development and production of weapons of war superior to those of our enemies. If we ever lose this superiority, then we can only expect to come out second best at the time of decision chosen by our enemies.

Our research and development program of necessity must be guided by this knowledge and should not fluctuate with daily events. Weapons as such become quickly outmoded and our production has to be geared to the necessity of the day. However, the searching and exploring beyond the known into the unknown for basic truths and the information and knowledge to build the weapons to defend ourselves cannot be worked as an accordion in keeping with daily events lest we find ourselves with inferior weapons in a time of great need. A school system based upon teaching only individual problems as they arise would not provide the fundamental knowledge with which to educate our people. We dare not follow such a procedure with respect to our research and development which vitally concerns our national security, when we face an enemy who will attack or move whenever it will advance Communism.

As taxpayers, Americans like to see what they are buying. Unfortunately in research and development this is not always possible. The products of research may take many years to appear and then appear in forms recognizable only to those familiar with the problems. It is quite often necessary largely to buy on faith in the field of research, which cannot guarantee positive results. Further it is sometimes necessary to safeguard knowledge at its source to insure its value for military application. This alone prohibits the making of such information public. The only justification for military research during peace time is to assure supremacy during war time. Clearly then we must have a realistic and continuing program of research and development to insure our security; and the people of the United States, and particularly the Congress, must be fully informed of these facts to insure continuity of an orderly and proper research program irrespective of the shifts in world events.

The complexity, intricacy and multiplicity of the weapons of today and those of tomorrow is such that it cannot be undertaken by the military services alone. There does not exist in the military establishment or the combined federal agencies sufficient scientific and technical manpower to provide the answers to all of the questions encompassed in insuring the security of America, nor is it reasonable to believe that it would be possible or prudent to attempt to assemble or sustain all the required knowledges directly under the auspices of the Federal Government. It is further extremely doubtful if sufficient technical manpower could be assembled in any one location to answer all the problems facing America today. The question then to be resolved is how can America efficiently conduct sufficient research and development to provide the weapons for our security. Fortunately for us, our enemies cannot mass-produce scientific information either, and we have demonstrated that we can conduct ours in a manner not to disrupt our economy or the normal processes of our educational systems. To obtain the knowledge and scientific information for our future security, the Armed Services must turn to the universities and industrial organizations of this nation. Requirements for the future indicate that through a nationwide network every available scientific and technical resource must be made available and utilized to insure this objective.

Ever increasing numbers of research and development contracts and programs are now being placed by the military

services with universities and industrial organizations throughout the nation. With this, a new approach and a new pattern to provide scientific and technical information for the military establishment is being evolved. It is one of extreme interest in that it marks acceptance by the civilian institutions of a joint responsibility for the solution of military problems through co-ordinated efforts of military, academic and industrial groups. It is appropriate, therefore, that we examine not only the form of contractual relationship but the method of implementation of research and development programs and the broad principles under which research and development may best be conducted for the military services by the civilian institutions.

For items of production the contracting pattern and principles are well established. However in research a new set of principles is found. Research by its very nature is to explore beyond the known; therefore, no organization, military or civilian, can guarantee the products of its research. When definite results and hardware items may be contracted for, the problem is no longer a research problem. The military services cannot say to the civilian institutions, "Here is a research and development contract. Provide us with defined items," as is possible under production type contracts. This exploration into the unknown, added to the complexity of the scientific and technical problems now facing the National Military Establishment (many produced by research and advancement in technical fields, in recent years) is such that the university and industrial groups cannot resolve the problems without the assistance of the National Military Establishment and its resources any easier than the Military Establishment can provide the necessary scientific and technical information without the university and industrial groups. Therefore, to maintain an adequate research program for our national security in the future it must represent a joint endeavor between the military and civilian institutions, both contractually and in its implementation.

First of all, it is necessary that this pattern of performing large scale research be evolved and carried out in a manner not to interrupt the normal peace time pursuits of the university and industrial groups and yet at the same moment to make available to the Armed Services the scientific and technical resources of these groups. To be most successful it must enjoy the freedom of movement of an industrial organization and the academic freedom of a university and at the same moment have available the resources of the Armed Services. Through this method operation can be conducted with the available resources and yet without the many restrictions common to Government operations. The program must be conducted in an atmosphere of a true partnership. It must be engaged in by research groups, particularly universities, to a large measure because of the realization of a responsibility owed to the security of this nation.

The military services must recognize their function of over-all guidance and planning, and, secondly and equally important, their role of a service function to the contractors in providing facilities, equipment, tools, and other resources to make possible the performance of the work. The programs must provide means whereby adequate thought for solution can be brought to bear on scientific problems of a military nature. It must enable scientists and engineers to maintain a close relationship and interest in research and development for the national security. The programs should be established in a manner to allow university and industrial groups to attack problems on a task force basis. Research groups should be encouraged to form a part of the over-all programs and to

maintain an interest in research and development so that they may promote the solution of problems of national security by increasing knowledge in those fields of endeavor important to the National Military Establishment. Technical personnel must not only be given problems but also a free hand to carry out research and development and pilot line production with a minimum of restrictions. In research and development it is desirable that pilot line manufacturing be carried out without technical inspection; in that the equipment is new and in some instances revolutionary and specifications would not exist or apply. The military services must, however, at all times retain the prerogative to decide in each individual case the inspection that will be required on equipment to be used or installed in the service.

The complexity of problems further demands that university and industrial groups across this nation must form an integral part of the programs and that the basic set-up utilize their ideas, experience, and knowledge in formulating over-all programs and in carrying out specific assignments. Further these groups can contribute greatly by having a voice in the design of technical programs and by enjoying participating membership on technical panels in the larger fields of endeavor, particularly in those fields where the university or industrial group possesses special knowledges and skills. Any program between the military establishment and the university and industrial groups in the field of research must allow for the creation of an environment suitable to draw from the scientific and engineering mind the greatest results. It must provide the establishment and maintenance of a highly flexible organization. It must provide a means by which the work of participating contractors and military groups can be assigned, evaluated, and co-ordinated. It must provide for the securing of maximum communication among research groups and between research organizations and the services. It must provide the best facilities and equipment possible for research projects. It must provide for the building of an organization adaptable to solving scientific problems of the future.

It is of interest to note that prior to 1941 the Army and Navy had limited personnel and funds for research and development work and there did not exist a means whereby the services of principal scientists throughout the country could be enlisted on problems of a military nature. In 1941 the President of the United States, by executive order, created the Office of Scientific Research and Development to carry out research and development and pilot line production of new and modified weapons for the Armed Services. This was the beginning of large scale participation by civilian groups in cooperation with the military services in research and development in this country for national security. Since that date great forward strides have been made in conducting large scale research by civilian institutions in cooperation with the Federal Government.

To implement these programs the military services, in addition to negotiating and awarding contracts and assigning work problems and tasks under the contracts, must guide the direction of the technical activities, unless this latter function is assigned a particular university or industrial group by contract. The military services must retain fiscal control and responsibility. It is desirable that the military services maintain constant communications with all phases of the work in the operation of laboratories and programs. This may best be accomplished by a representative of the military establishment possessing an understanding of the fundamental and basic principles of conducting research and development and one sympathetic to research and development.

Again research and development cannot be treated as production. It must be the responsibility of the service representative to administer the contracts from the point of view of the contracting agency including contractual, legal, fiscal, security, inventories and matters of operation and maintenance, and to bring the resources of the National Military Establishment to the contractor, all in accordance with assigned contracts and tasks. The military groups must determine the scope and activity at which the technical work is to proceed. It is important in this connection that the result desired be outlined, but not the specific method(s) for obtaining these results. In the operation of such programs it is imperative that the military services supply a liberal democratic type of broad technical guidance. It should be presented in a manner which does not prohibit the growth of new ideas essential to progress. It should further be handled in a manner which does not attempt to prescribe the thinking of an activity but more nearly supplies the broad technical guidance and direction of effort of work. It is desirable that it provide a means whereby scientists of the working level can communicate in that scientific progress can best be achieved when scientists at the working level are brought together.

It is desirable that the contracts embody as few limitations and restrictions as legally possible to permit freedom of initiative within broad assignments. This is highly desirable for maximum scientific progress. In this connection, however, it is necessary that the military services work closely with the research and development contractors engaged in the programs to prevent undesirable divergence in procedures and objectives, to insure uniformity of practices, to give preapprovals of work, and to make on-the-spot decisions to allow for successful, speedy operation. By this means the work can be greatly accelerated and at the same moment universities and industrial groups protected from serious subsequent disagreement with the military regarding the necessity of expenditures incurred or the necessity of the work performed.

This method of doing large scale research enjoys an impressive record established in the relatively short period it has been employed in this country. However, it would not be realistic to imply that this type of operation is infallible or that the pattern alone is the only reason for the success of such an operation. The success of cooperative type research between the university and industrial groups and the Federal Government for national security lies not only in the form of contractual relationships but in the actions of those who implement it. It must enjoy the wholehearted enthusiasm of the sponsoring agency and of all the contractors and associated groups. It must enjoy the cooperation of talented scientists. It must represent an outstanding example of team work. It is a pattern that will serve, if properly planned and executed, to keep America technically sound, strong, and ahead of her enemies.

Much of the strength of this type operation lies in the ability of such programs to attract and hold men of the highest caliber who find in its freedom of action inspirations to great achievement. Such programs, in addition to possessing persons of outstanding scientific and technical qualifications, must have personnel generously endowed with a personal capacity for the tactful guidance of top grade scientific personnel. This is important in that scientists, even more than most men, must be tactfully led.

They are mental explorers and adventurers into the unknown. No longer are there unknown lands and seas to stimulate man's curiosity as in the time of Marco Polo, Columbus, Henry Hudson and many others of a great tradition.

But today there are frontiers more challenging than geographical ones. The scientist is a spiritual descendant of the old explorers. Today he pushes out beyond a wide frontier where lies not new lands and seas but an unknown universe. This type of research program offers a great stimulus to the imagination of the research scientist in that the scientists enjoy the opportunity to follow the irresistible lure of the unknown largely unimpeded within broad areas. These programs may be carried out by university and industrial groups employed either on a full or part time basis in a manner not to interfere with their normal peace time pursuits, offering one of the better ways to conduct large scale research and development and making available to the military services the top level scientists of the nation.

There is, and there always will be, a definite need for government laboratories, but to answer all the problems now facing this nation no longer can be considered the sole responsibility of a few groups or government agencies. All of the nation's scientific and technical talents must be utilized in an orderly large scale scientific endeavor.

The number of persons actually engaged in research in this country now totals only 150,000 or approximately 1/10 of 1% of our national population. These must be utilized most efficiently in their peace time endeavor to keep America scientifically and technically ahead of her enemies. Irrespective of the type program we employ in peace or in war we will not be able to do or develop all the things we would like to for the defense and security of our nation because of limitations of available scientific manpower, resources and budgets. This cooperative type program is employed with various modifications by the Armed Services and certain other Federal Agencies. It has been employed quite extensively by the Department of the Navy, using a nationwide network of university and industrial organizations. Many technical firsts emanating under these cooperative programs, for the National Military Establishment, have demonstrated that such programs offer one of the better solutions to the problem of utilizing our top level scientific manpower to insure national security while disrupting as little as possible our normal peace time pursuits.

Our efforts must be expended constantly in a most constructive and effective manner. Our organizations, in peace or in war, must embody the means and determination to attain the maximum co-ordination between the government, the universities, and the industrial organizations. Only in this manner can we obtain the maximum potential available with what we have, build the weapons necessary for our defense, and replenish the storehouse of basic scientific information. Only in this manner can we insure the security of America.

SERVO MECHANISMS IN AIRCRAFT

ACKNOWLEDGMENT

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The design of automatic pilots has been one of my main pre-occupations since the year 1925, but I do not think this is my sole reason for regarding the control of the airplane itself as the main application of the art of servo mechanism in aircraft. It may, however, be accepted as justification for my not attempting to exhaust the field of other applications in this paper.

Although servo mechanisms have been used for a considerable time in the form of marine steering engines and, even earlier in the governor of Watt's steam engine — analyzed mathematically by Clerk Maxwell in 1868—the name servo mechanism, according to the *Shorter Oxford Dictionary,* dates from 1889. This dictionary defines the term as "An auxiliary motor, e.g., one used for directing the rudders of a Whitehead torpedo, or the reversing gear of a large marine engine." However, it is only in the last two decades that the potentialities of the art have begun to be recognized. This revolution of thought is based primarily on the thermionic valve, but it did not occur until the need for improving weapons, to meet the ever increasing speed of modern war, forced designers to recognize that the thermionic valve could be used for controlling small electric motors as well as for amplifying signals in the communications industry.

As a result of this revolution of thought, the servo mechanism has passed from the field of sporadic mechanical invention to a part of the science of communications engineering. This change has speeded up the revolution by making available, in the field of servo mechanisms, the well developed theory of circuit design already produced by the earlier application of the thermionic valve in the communications field. Each branch of engineering develops its own language and habits of thought. It is therefore not surprising that the marriage of the two arts has led to a babel of confusion in the terminology. This is exemplified by the statement of I. A. Getting, of the Massachusetts Institute of Technology: "It is nearly as hard for practitioners in the servo art to agree on the definition of a servo as it is for a group of theologians to agree on sin." Various attempts are being made to define rigidly the terms required in the field of servo mechanisms but, since the art is advancing so rapidly, it is questionable whether this can be done at the present time without prejudicing progress. Any rigid definition of the term "servo mechanism" is in danger of excluding a potentially useful class and thus discouraging development of that class.

I think it can be agreed that a servo mechanism is a slave mechanism; that

is, a mechanism doing some work in accordance with instructions received from a higher authority. Now the information incorporated in these instructions may include or not include the action of the slave. Thus we are presented with two broad classes which have been called closed-sequence and open-sequence systems. The present tendency is to restrict the term servo mechanism to the first of these classes in which the instructions are based upon a comparison between the desired and the actual performance —this difference being the error of the system. Although in a great many cases the derivation of this error is essential for the accuracy required, there are, in my opinion, strong grounds for preferring the open-sequence system in certain circumstances and it would be a supreme mistake to allow such systems to be declassed so that designers were discouraged from using them.

The same classification of control systems applies in the organizational affairs of man and in the control systems of the individual living organism. Thus a commander of an army could not function if every action throughout his command had to be continuously observed by him and his orders had to be conditioned by the actions of each individual soldier. Such an organization would break down for two obvious reasons—intolerable information traffic congestion at G.H.Q. and intolerable delay in dealing with local situations. To meet these difficulties, we have had to introduce the principle which I think is aptly designated by the word devolution. We shall see that this principle of devolution is incorporated inevitably in most control systems except the very simplest and that it involves open-sequence control.

The present literature of servo systems is based mainly on simple systems and in my opinion tends to deny the open-sequence system its proper recognition. When it is admitted at all, it is generally in the form of some exceptional dodge to deal with exceptional circumstances instead of a sound general principle which should be employed in well understood circumstances. As an example of such dodges, I would mention a device often referred to as disturbance compensation. When an oven temperature is controlled by a simple closed-sequence system, there will be a rapid drop in temperature every time the oven door is opened. The classic treatment for reducing all deviations, whatever the cause, is to increase the stiffness of the control. In the technical language of the art we try to increase the loop gain, by which is meant the degree of variation of the supply of heat for a specified observed error in the temperature. But the classical treatment also tells us that we cannot go too far in this direction without running into instability; we reach a condition when the temperature instead of resting at the desired value oscillates about this value and, if the system is linear, these oscillations will continuously increase in amplitude. All practical systems are, of course, non-linear and, in fact, the oscillations cannot increase beyond the stage when the controller is employing the whole available range of control; in technical language the system is saturated. To minimize the drop in temperature when the oven door is opened. we can arrange to turn on extra heaters whenever the door is open. This is the device known as disturbance compensation. It will be recognized as a particular application of devolution or open-sequence control.

A more quantitative application of the principle of devolution, also in the field of thermostatic controls, is sometimes used in the control of the internal temperature of a building. Sudden changes in the outside air temperature will cause shock disturbances in the controlled internal temperature because of the delay before the magnitude of the disturbance is adequately sensed by the internal error detector. Again there is

a limit to the extent to which this disturbance can be controlled by increasing the loop gain without introducing instability. But if a signal is passed to the controller from a thermometer exposed to the outside air, the necessary correction can be fed forward before any error in the internal temperature occurs. Here we have an example of the need for devolution to avoid the delay involved in the closed-sequence system. This example explains why the device of devolution in a control system is sometimes referred to as "feed forward" in contradistinction to the "feed back" characteristic of the closed-sequence system.

Human muscular control supplies a more striking example of the principle of devolution. All voluntary actions are directed by the higher brain center with which consciousness is associated. But all communications through this center are subject to a delay varying according to the complexity of the situation in which a judgment is exercised, but of the order of a quarter of a second in the simplest situations. This sets an upper limit to the frequency of disturbance which can be controlled by a communication system involving feed back. This can be demonstrated by requiring a subject to move a pointer so as to keep it aligned with a second pointer moved in a random fashion by extraneous means. The random movements can be represented as a composite pattern of a number of different frequencies. If none of these frequencies is higher than about a quarter cycle per second, accurate performance is comparatively easy, but when higher frequencies than one cycle per second are involved in the pattern the task becomes impossible. The dividing line is somewhere about half a cycle per second and varies a little according to the reaction time of the subject and such factors as fatigue. It is thus clear that, without involving some other principle, it would be impossible to account for the speed of touch typing or playing a piano. The principle involved is devolution to the lower nerve centers operating on local feed back through proprioceptors or kinæsthetic sense organs. A little reflection will show that almost every human muscular action—walking, talking, writing, playing games—is controlled on this devolution principle and that we should be very slow, awkward and stupid without it. Some animals appear to be born with their proprioceptor control systems highly developed, but in man they are developed slowly by training and the accumulation of callisthenic memory.

We can now examine how these principles of classical closed sequence and devolution or open-sequence control may be applied to a specific mechanical problem—the stabilization of a platform in a moving vehicle. To maintain a platform locating a bombsight, a camera, or a radar scanning system, in a constant plane it is necessary to stabilize it about two independent axes by a gimbal system similar to the mounting of the ships' candle. To avoid unnecessary complexity in the presentation of the principles involved, I shall discuss the question on the assumption that the vehicle moves only about one axis.

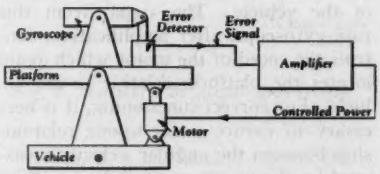


Fig. 1. CLOSED-SEQUENCE SYSTEM, SINGLE AXIS.

In Fig. 1 is shown a conventional closed-sequence arrangement. The platform is pivoted about an axis parallel to that about which the vehicle moves and is located by a motor. A free gyroscope is carried on the platform and is coupled

to an error detector which generates an error signal representative of the displacement of the platform relative to the gyroscope. This error signal is passed to an amplifier the output of which controls the motor. Thus, the motor is continuously driven to reduce any error detected. If we assume for the moment that the direction of the gyroscope axis remains constant, the platform is stabilized. Since the system is entirely error operated, errors are unavoidable.

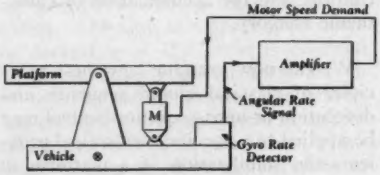


Fig. 2. OPEN-SEQUENCE SYSTEM, SINGLE AXIS.

Fig. 2 represents a crude open-sequence system for achieving broadly the same purpose. Though the application of the principle of devolution to this problem does not necessarily involve the substitution of a different type of gyroscope for sensing the disturbance, I have shown a form of gyroscope which measures the angular rate of disturbance of the vehicle. The signal from this rate gyroscope, after amplification, controls the speed of the motor which again locates the platform relative to the vehicle. For correct functioning, it is necessary to ensure a one-to-one relationship between the angular velocity measured by the gyroscope and the resulting angular velocity imparted to the platform.

The limitations of open-sequence operation are readily apparent from a consideration of the scheme of Fig. 2. Thus, if the platform is initially disorientated there is nothing, so far, in the system to restore the alignment. Moreover, extraneous disturbances, other than the angular movement of the vehicle, such as a load applied to the platform or a variation in the power supply, will modify the performance in such a way as to introduce disorientation. The advantages of the open-sequence operation are that errors are not required to initiate action and that much faster action can be achieved since the stability problem of the closed sequence, or closed loop as it is often called, is not involved. I shall have more to say later about closed-loop stability.

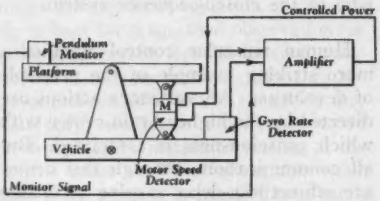


Fig. 3. MONITORED OPEN-SEQUENCE SYSTEM WITH LOCAL CLOSED LOOP.

Fig. 3 shows a development of the open-sequence system on the lines of human muscular control. To ensure better correlation between the angular rate measured by the gyroscope and the angular rate imparted by the motor, a "kinæsthetic organ" in the form of a motor speed detector has been added. This device provides a signal proportional to the speed of the motor which is used to back-off the gyro rate signal. It should be noted that accurate setting of the amount of this local feed-back signal is necessary to ensure the required one-to-one relationship. This is analogous to the need for training in the acquisition of human skill. As a further refinement, the equivalent of the supervision of the human eye has been added in the form of a pendulum "monitor" carried on the platform. Any "steady state" misalignment of the platform is thus detected and a relatively weak signal, backed off by the resulting signal

from the motor speed detector, keeps the platform moving slowly until the pendulum signal subsides to zero.

It will be observed that the short-term or dynamic control is still open sequence, as in Fig. 2, but that the long-term performance is now closed sequence through the pendulum monitor. Since a pendulum is disturbed by every acceleration of the vehicle, it is quite useless for providing short-term stabilization. On the other hand, the gyroscope—either the displacement type of Fig. 1, or the rate type of Figs. 2 and 3—is useless for long-term stabilization due to its inevitable slow wander and due to the rotation of the earth and the changing direction of the vertical as the vehicle moves over the surface of the earth. This last proviso may sound a little academic until one realizes that the modern jet airplane could very nearly put a girdle round the earth in 24 hours.

The arrangement of Fig. 3 is thus a compromise between open- and closed-sequence control in which both the gyroscope and the pendulum are used within the limits of their capabilities and in which the dynamic performance is not dependent on platform error as in the closed-sequence arrangement of Fig. 1. It will now be appreciated that the closed-sequence system of Fig. 1 is an over simplification, in that it assumes a constant direction for the gyroscope rotor axis. In fact a gravity monitor is also required in this case to take care of the long-term performance. The gyroscope has to be provided with an auxiliary closed-loop system to cause it to precess in response to any error detected between its datum and that of a pendulum. Thus, the apparent simplicity of Fig. 1 is illusory and the compound system of Fig. 3, involving the principle of devolution, appears as a better system.

Closed-Loop System.—Because closed-sequence operation is generally required, at any rate for the long-term performance of a control system, the theory of the closed loop has been thoroughly developed and many authorities restrict the name servo mechanisms to systems operating on this principle. The uses to which closed-loop servo mechanisms are put are extremely various and include: (1) automatic regulation; (2) power amplification; (3) remote control; (4) stabilization; (5) computing; (6) transducers in which a mechanical representation of a non-mechanical quantity is required; and (7) indicating instruments. The motor employed may be electric or fluid-operated. The modulation means may be electric, fluid, or mechanical, and, in the latter case, they may be employed in the output train of the motor as in the case of the infinitely-variable and reversible gear. Whatever variants are used, the closed-sequence system may be represented by the apparently simple schematic of Fig. 4.

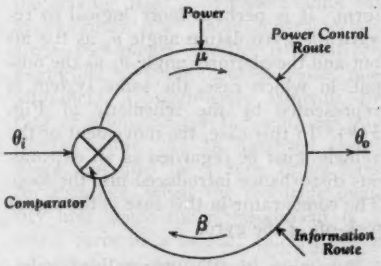
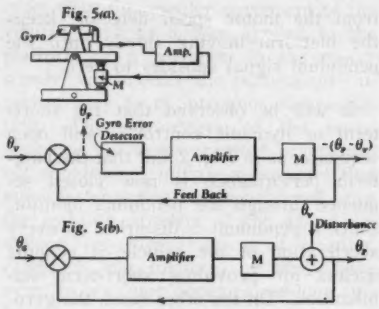


Fig. 4. SCHEMATIC OF CLOSED-LOOP SYSTEM.

In Fig. 4, a mechanical output quantity θ_o, position, speed or force, is controlled in conformity with an input quantity θ_i, by continuous derivation of an error signal in a comparator to which the output quantity is led by a route labelled "information route," the error signal being led by an independent active route, labelled "power control route," back to the output. It should be observed that the same system may be represented in more than one way by the

same schematic, according to which quantities are regarded as the input and controlled quantities. Thus, in the system of Fig. 1, the angle of the vehicle θ_v may be regarded as input, the difference between the platform and the vehicle $(\theta_p - \theta_v)$ being the output which is required to be equal and of opposite sign to the input in order to ensure that the platform angle θ_p shall be maintained at zero. In this case, the comparator is comprised by the structure, since the displacement of the platform—the error—is the difference between the movement of the vehicle and the counter movement provided by the motor. The sequence schematic then takes the form of Fig. 5(a). It should be noted that, in this conception, although the loop output is the relative angle of the platform, the objective of the system is the suppression of the platform angle θ_p. Moreover, the information route, or feed back, is in this case utilized also for the transmission of mechanical power to the platform. It is perhaps more logical to regard the gyro datum angle θ_g as the input and the platform angle θ_p as the output, in which case, the same system is represented by the schematic of Fig. 5(b). In this case, the movement of the vehicle must be regarded as an extraneous disturbance introduced into the loop. The comparator in this case is the signal pick-off of the gyro.

Reverting to the generalized schematic of Fig. 4, it will be observed that by routing the power and the information independently, each circuit can be designed to meet its specific requirements without being burdened with the responsibility of the double purpose requirement of the open-sequence system. Thus the requirement of fidelity is confined to the information route which need have no power loading. The power route must release the required power with sufficient sensitivity, but fidelity in regard to linearity and immunity from disturbance of output by ambient conditions or variations of supply or loading is not a requirement. The power control route, however, is required to possess datum stability (using the word stability in its non-technical sense), as regards its input. Thus any variation in its input required for zero output must be referred to the input comparator and thus included in the information route.



ALTERNATIVE SCHEMATICS OF SYSTEM SHOWN IN FIG. 1.

Certain broad principles can be established from a purely static consideration of the loop. Thus, if we designate the transfer ratio of the power route by μ and that of the information route by β, as indicated in Fig. 4, the output quantity is referred back to the input in the proportions β and $\frac{1}{\mu}$ by the two routes. Thus the ratio of falsely routed intelligence to correctly routed is $\frac{1}{\mu}$ to β, or 1 to $\mu\,\beta$. The error thus approaches zero as $\mu\,\beta$ approaches infinity. Now the quantity $\mu\,\beta$ represents the gain round the complete loop and is thus known as the "loop gain." Clearly we should use the highest practicable loop gain. Extremely high fidelity can be obtained by the use of a high loop gain provided the information route is itself of high fidelity. Often, however, it is necessary to change the form of the output quantity; for example, to change from position or speed to an electrical representation and

this requires the interposition of some form of instrument the accuracy of which circumscribes the accuracy of the system. Such instruments are sometimes referred to generically as transducers. For the highest fidelity it is desirable to restrict such transducers to the power route, in which case the input and output quantities are of the same form, e.g., mechanical displacements. This principle of stricting all transducers to the power route is the basis of all null-reading measuring systems.

Stability.—In a closed-loop servomechanism, the direct consequence of a misalignment is generally a force or torque after amplification of the misalignment signal. Generally this results in a rate of change of the motor velocity, and, if θ_o is a position, two stages of integration are involved in the power route. The result is that, in the absence of any variation in the input, θ_i, the mass of the motor and its load is subjected to an acceleration depending on displacement. Thus, if the whole loop is sufficiently linear, its dynamic state will approximate that of a mass located by a spring; that is, an undamped harmonic oscillator. Now, if there is any additional time lag in transmission round the loop, the restoring force will be late and the oscillator will clearly be unstable; that is, its amplitude will spontaneously increase. It is thus apparent that, apart from the specific requirements of the two routes, there is an additional requirement that the closed loop shall be sufficiently stable. In general, provided the performance of the individual elements can be expressed mathematically, the performance of the closed loop can be expressed by a differential equation. If also all the components are linear and the relationships are invariable, the characteristic equation will have constant coefficients. Such a system is capable of precise analysis and prediction.

I have shown that an idealized simple position-locating loop constitutes an undamped oscillator. Clearly if the feed back includes a component of motor speed as well as position, the restoring force will act earlier and the oscillator will be damped. In either case the characteristic differential equation is of the second order and the loop may be classified therefore as a second-order loop. If, however, the output quantity is velocity, the idealized characteristic equation is of the first order representing a continuous subsidence of the fed back quantity and the system may be called a first-order loop. A first-order loop may also be approximated with a position feed back if the motor characteristic is such that its velocity is proportional to the misalignment. The infinitely-variable gear, as a means of modulating the output of a constant-speed motor, is an example of such a system in which the misalignment input is the displacement of the driven wheel from the axis of the driving disc. A hydraulic motor can approximate the same characteristic since the motor inertia is relatively negligible and the control valve misalignment approximately controls the rate of admission of the working fluid to the motor. As an idealized system there can also be a zero order loop; for example, when the fed back quantity and hence the misalignment is itself a force or a torque. Such a system is sometimes referred to as a torque amplifier. It is one form of power control that has been employed to operate the control organs of airplanes.

All practical closed-loop systems involve a characteristic equation of a higher order than their nominal order. As the loop gain is increased in pursuit of greater precision, inertia and elasticity of light rigid components become important, and, on the electrical side, stray inductance and capacity can no longer be neglected. When these effects are taken into account the order of the characteristic equation rises. Thus all

closed-loop systems are capable of spontaneous oscillation under certain conditions. We shall see that this always sets an upper limit to the loop gain that can be employed.

I have referred to the loop gain $\mu\beta$ as if it were a simple ratio. This is only the case in an ideal zero order loop. In any practical system it must be regarded as a transfer function, that is, the relationship of two quantities which are related in time by a differential equation. If one quantity is a simple-harmonic oscillation, a second quantity, related to the first by a linear differential equation of constant coefficients is also a simple-harmonic oscillation of the same frequency. In general, these two oscillations will reach their peaks at different times; they are said to differ in phase. It is thus apparent that for any one frequency the loop gain may be represented by two quantities, the amplitude ratio and the phase difference. These two quantities may again be represented by a vector of which the length corresponds to the amplitude ratio and the angle corresponds to the phase difference. If now the frequency of the oscillation is slowly changed, the representative vector will also change and the free end of the vector will sweep out a locus. If this locus is marked out with a scale of frequency it becomes a complete representation of the transfer function from the one quantity to the other. A typical transfer locus representing the loop gain of a first-order system containing unavoidable lags is shown in Fig. 6. Such a diagram is known as the Nyquist plot of the open loop.

We may now consider what to expect if the Nyquist plot passes through the point -1. Physically, this means that at some frequency the loop gain will be a simple sign reversal. But, since we are dependent upon a sign reversal of the feed back in the comparator, a second sign reversal results in the feed

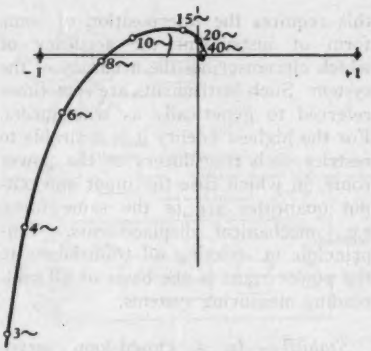


Fig. 6. LOCUS OF TRANSFER FUNCTION.

back supplying exactly the signal required for its own support independently of any demand, once the loop is closed. Such a system will thus oscillate spontaneously at the frequency for which the transfer is equal to -1. This is the physical basis of the Nyquist criterion of stability. A rigid statement of the Nyquist criterion in non-mathematical terms is impossible owing to the possible complexity of the Nyquist plot. For most purposes it is sufficient to say that, if the curve embraces the point -1, the system will be unstable when the loop is closed, but that if it excludes this point, as in Fig. 6, it will be stable. Thus any loop will become unstable eventually if the amplification is steadily increased. The difficulty in applying the criterion, in the over simplified form which I have stated, arises in the case of conditionally stable systems, that is, systems which are only stable over a specific range of amplification. It will be appreciated that a loop containing any unstable element, if stable for any amplification, must be conditionally stable since it will go unstable if the amplification is sufficiently reduced to allow the unstable element to perform uncontrolled.

It thus appears that there are conflicting requirements in the design of every closed-loop system. To reduce the error

on which the system depends for its operation, we want to make the loop gain as large as possible and to ensure stability we must keep the gain within the limit set by the Nyquist criterion.

Servo Trains.—Most control systems, mechanical or otherwise, are found on close analysis to consist of servo-trains, that is an assembly of several closed-loop systems forming a major loop open or closed. In mechanical servo-trains of this kind a human operator often provides one of the elements, as when a helmsman steers a ship by compass. In all such cases the human operator can be replaced by a servo mechanism and it is often desirable to do so either for reasons of economy or because the range of successful opening frequency can be increased by eliminating the human discrimination lag. The main applications of servo mechanisms in aircraft are those which have been introduced to take over functions of the human pilot. Thus the automatic pilot is used primarily as a regulator of the flight attitude, the airplane control organs supplying the motive power. But the automatic pilot is also a local closed-loop system, with its own motive power, for amplification of the signals of the gyroscopic detectors to movements of the control organs. Within the automatic pilot many more local closed-loop systems are employed for computing purposes and to provide maneuverability.

The Automatic Pilot.—The earlier automatic pilots were comparatively simple devices arranged to stabilize the airplane in straight flight. Two free gyroscopes were employed to define a frame of reference and the disturbances of the airplane were detected by pneumatic error detectors, one attached to each of the gimbal rings of one gyroscope, the third being operated by the second gyroscope. Pneumatic rams were used for the servomotors and the feed back was provided by a mechanical connection between the servomotor and the "follow-up" frame on which the gyroscope was mounted. Long-term monitoring was provided by gravitational devices operating directly to precess the gyroscopes about the two horizontal axes. The arrangement thus followed closely that of Fig. 1, and was, in fact, a further development of the Whitehead torpedo system. The azimuth datum was at the mercy of the random precession of the azimuth gyroscope until, in 1927, the principle of monitoring the gyroscope from a magnetic compass was introduced. This principle has since been developed as the basis of the modern aircraft compass, the speed and acceleration of the airplane rendering the principle of the marine gyro-compass inapplicable.

These early automatic pilots were produced principally for stabilizing bomber aircraft and maneuvering was limited to slow changes of pitch datum, produced by displacement of the datum of the longitudinal gravitational monitor, and slow turns executed without banking. An ingenious device for countering the effect of the centripetal acceleration on the lateral gravitational monitor was introduced in 1933. This device was based on the principle of the Lanchester pendulum, wherein a gyroscopic torque, proportional to the rate of turn, is arranged to balance the torque produced by the centripetal acceleration acting on the pendulum.

As the streamlining of airplanes progressed the method of flat turning, to bring the airplane to the correct heading for the release of the bomb, had to be abandoned because, after a discrete change of heading, the airplane continued to move in the same direction and only subsided on to the new course with a time lag of about 15 or 20 seconds. In nautical terms, there was too much leeway. Thus, both for military and for civil purposes the need emerged for an automatic pilot capable of executing correctly co-ordinated turns and generally of a high degree of maneuverability.

Now the co-ordination of turn requires that the tangent of the angle of bank shall be proportional to the product of the rate of turn and the forward speed. In general, the designers of automatic pilots have been reluctant to rely on computation requiring accurate measurement of the forward speed and many alternative devices have been tried. Of these, perhaps the most successful, dating from 1938, relies on the principle of disturbance compensation which I have described. In this system, the error in co-ordination is detected by a lateral pendulum, the signal from which is used to monitor the rate of turn, the angle of bank being the quantity controlled by the pilot's input. Since, however, a high loop gain could not be employed on the rate of turn control without introducing oscillatory instability, a datum disturbance compensation to the rate of turn demand was introduced proportional to the ordered angle of bank and inversely proportional to a preset estimated forward speed. By these means the required degree of precision of co-ordination was obtained without requiring a prohibitive loop gain in the rate of turn control.

The increasing complexity of the modern automatic pilot has necessitated resort to electrical signalling systems and electrically-driven gyroscopes. Generally, this change has been accompanied by a change over to electric motors to provide for a single source of power. This has provided a degree of flexibility in design and adjustment which could not have been easily attained by the original pneumatic systems. As a result, the automatic pilot is capable of correcting the inherent lack of damping in yaw of the modern airplane, a task generally beyond the capacity of a human pilot and of maneuvering up to and through the barrier of sonic speed.

Among the many difficulties with which the designer is faced, is the fact that gravitational monitors are of very limited use at very high speeds. With our earthbound habits of thought we are apt to regard the pendulum as a device which seeks the vertical and which may be somewhat disturbed by accelerations of its mounting. It is more realistic to recognize that the resultant gravitational field inside a moving craft is solely produced by the resultant external force applied to the craft and that gravitation is not an external force but a convention of the system of axes we choose to call unaccelerated. Thus, in an interplanetary vehicle there would be no gravitational field other than that caused by the reaction of propelling rockets. The airplane flying at 50,000 ft. is not yet an interplanetary vehicle but, unless one can be assured that it is not accelerating relative to axes fixed on the ground, the pendulum cannot be relied upon to give any indication of the vertical. This does not mean that the pendulum is useless but rather that gyroscopes must be relied upon for much longer times to achieve the state of unaccelerated flight in which the pendulum can perform its monitoring function. Since the magnetic compass is also gravity dependent—the magnetic field defines a line and not a plane—the same remarks apply to magnetic monitoring of azimuth.

Electric automatic pilots have generally relied upon the thermionic valve for signal amplification and for the required "shaping" of transfer functions. Recently, the magnetic amplifier has been steadily displacing the valve and prototype autopilots are flying with all valves eliminated. The magnetic amplifier relies on the ability to modify the performance of an inductance by variation of the degree of saturation of the core. This saturation is controlled by a direct-current winding in which the alternating flux is balanced. By the use of regenerative feed back, very useful power amplification can be obtained in a single stage and several stages can

be used in cascade. For power applications the technique is competitive with the valve amplifier in respect to size and weight and is to be preferred for reliability. The main difficulty in the use of magnetic amplifiers is the inherent time lag involved in varying the controlling flux. However, by the application of loop theory, a somewhat complicated system of feed-back can produce a cascade amplifier to handle the power required in an automatic pilot with a lag of the order of ten milliseconds when used with a 400-cycle supply. By greater refinement or by the use of a higher supply frequency, still quicker response is practicable. It is therefore probable that magnetic amplifiers will find a wide field of application apart from aviation.

Blind Approach.—Recently, the automatic pilot has been developed to seek and follow a track defined by radio, primarily for blind approach in fog. With this development the airplane becomes a component in yet a wider loop and the wings of the airplane provide the servo power. These applications of the servo art provide the most complex stability problems. The main component, the airplane itself, varies widely in its transfer functions due to the range of speed and altitude over which it has to operate. Moreover, it is sometimes an inherently unstable component. Riding the radio beam at short range from the transmitter provides a still more complex problem, since it involves relationships no longer expressible by differential equations with constant coefficients because the range from the transmitter and the tolerable errors are continuously changing. In addition the track, defined by the radio, is distorted by interference patterns caused by unavoidable reflections when the airplane is close to the runway and the greatest precision of locations is required. This introduces in an acute form the problem of discriminating signal from "noise," i.e., the useful intelligence from spurious signals. Fortunately, a "noise-free" representation of the rate of change of the error from track can be obtained from the aircraft compass since the direction of the track is known. It is thus not necessary to accentuate the "noise" by differentiating the error signal in order to obtain the required loop stability.

In spite of the difficulties of the problem, the stage has now been reached that automatic approaches under conditions of bad visibility can safely be made provided the last hundred feet of the "let down" can be made by visual guidance. By the use of suitably-designed airdrome lighting systems, landings are practicable in almost every condition of visibility because the thickest ground fogs are generally of limited height and, provided the airplane has been correctly placed by the automatic approach system, the position of the lights can be recognized by the patches of illumination on the top of the fog layer. It may confidently be predicted that in another ten years, complete automatic control will be a normal method of effecting the landing maneuver.

Any control system involves a risk of malfunctioning due to failure of one of the components in the train and, when so many components are involved, as in the case of automatic landing, this risk is considerable. It is, therefore, essential that any system of blind landing—or even of blind approach—should be so monitored that a failure of any part of the system will become apparent to the pilot before a dangerous situation has developed. If possible, such a monitoring system should comprise an entirely independent train of communication but, provided the component reliability can achieve a high enough standard, it may suffice to ensure that each section is so monitored that a fault in that section becomes apparent.

Should it prove desirable to use an entirely independent train of communi-

cation, the system known as Ground Control of Approach — or G.C.A. — could be employed. In this system, the position in plan and elevation of an approaching airplane is continuously observed by radar operating on the ground and instructions are communicated by radio-telephone from a trained observer to the pilot. This system was extensively used for military airplanes in the later stages of the last war and, although it does not provide an absolutely safe method of control, it could undoubtedly supply the required monitoring for an independent automatic approach system.

Power Controls.—In the early days of airplanes, the control surfaces—rudders, elevators and ailerons—could be moved easily as required by direct mechanical connection from the cockpit controls — the rudder bar and the control column, or, as it came to be known, the "joy-stick." But, as the size and speed of the airplanes increased, the operating forces naturally became heavier. At first, this difficulty was easily met by the device of aerodynamic balance, that is, the extension of some of the moveable surface in front of the hinge line so as to balance part of the aerodynamic forces about the hinge. Close aerodynamic balance was never practicable, however, because the effects are essentially non-linear; the amount of balance surface required varies with the angle of the control surface. However, until quite recently the ingenuity of the aerodynamic designer has been capable of keeping the operating forces within the capacity of the pilot over the required range of angles and flight speed without introducing the instability of overbalance.

The rapid increase in the speed of flight which has taken place in the last decade has produced a situation in which aerodynamic balance no longer suffices, for, it must be remembered, these aerodynamic forces increase with the square of the speed. Thus, in the larger modern airplanes, servo mechanisms are required to enable the pilot to move the controls. These servo mechanisms are known as power controls and are the counterpart of the steering engines of the marine art. Aerodynamic servo controls, suggested by Flettner some 30 years ago, have been in use for some time. In these aerodynamic servos, the pilot's rudder bar, for example, instead of being connected to the rudder, is connected to a flap or tab hinged to the rear of the rudder. Thus, the tab modulates aerodynamic power to move the rudder and the feed back is provided by the resulting hinge moment of the rudder. Such controls are now generally known as "servo tabs."

In a further elaboration of the servo tab, known as the "spring tab," the rudder bar is connected differentially to the tab and the rudder so as to provide an additional mechanical feed back and the relative movement of the tab is restrained by a spring. With this arrangement, the spring dominates the feel at high speeds, when the aerodynamic forces are large, and provides a rudder-bar reaction substantially proportional to the rudder angle, while, at low speeds, the spring is but slightly deflected and the reaction approximates the load on the rudder. A further advantage of the spring-tab arrangement is that the gearing between the rudder bar and the rudder decreases as the airspeed (and, consequently, the spring deflection) increases. It thus provides a reduction in the gain of the airplane control loop to offset partially the increase in the aerodynamic part of the loop.

These servo tabs and spring tabs, however, do not provide a complete solution of the problem because the forces required to move the tabs themselves are not negligible. This difficulty

can be met to some extent by aerodynamic balance of the control so as to reduce the size of the tab required and again by aerodynamic balance of the tab itself. However, in transonic flight the flow pattern changes drastically, with the result that the centers of aerodynamic pressure on the movable surfaces also change drastically. It is therefore extremely unlikely that close aerodynamic balance can be achieved in this regime.

As a result of these difficulties and also for reasons connected with the problem of flutter, that is, unstable oscillations due to accidental aerodynamic loops, the present trend is towards hydraulic motors for power controls. Hydraulic motors seem ideally suited for the purpose on account of their overall lightness and their low inertia. It cannot be said that really satisfactory designs of hydraulic power controls have yet been achieved. The two main difficulties are to provide against catastrophic malfunctioning in the event of any failure and to provide the required threshold sensitivity of performance. An airplane cannot be stopped in transit, as a ship can, to repair a fault in the steering engine. It is therefore necessary to design a power control system so that the pilot can retain control in the event of any foreseeable failure. This requirement can only be met by duplication of all parts of the system in which failure can occur. It is also necessary to ensure that a runaway cannot occur in any circumstances since the application of full control at high airspeed would certainly cause structural failure. Manual reversion can be employed for some airplanes but in most cases the forces would be well beyond the control of the human pilot. Thus, the power control must be designed so that a faulty motor cannot prevent the remaining serviceable motor from exercising effective control. These safety requirements set a difficult but not insoluble problem.

At modern flight speeds the control organs, especially the elevator, require to be located to a precision of about a tenth of a degree, or, say, one part in 500 of the range of control. In the presence of unavoidable friction causing threshold insensitivity and because of the "dead spot" associated with the reversal of action of hydraulic valves, this is an arduous design requirement. Naturally, it is necessary to increase the loop gain as far as the loop stability will permit and generally it is found that the elasticity of the airplane's structure provides stray feed back couplings. It is, therefore, not surprising that many power control systems fall short of the required degree of precision of location. The resulting imperfection is generally most noticeable when the airplane is flying under the control of an automatic pilot which is sufficiently sensitive to set up a steady small amplitude oscillation or "hunt" of the whole airplane as a result of the extra phase lag introduced into the transfer function at small amplitude. This is a situation which cannot be rectified by modification of the transfer function of the autopilot local loop; the remedy necessarily lies in the improvement of the threshold performance of the power control loop.

Flutter.—We are all familiar with the phenomena known as Aeolian tones without perhaps realizing that the singing telegraph wire is an example of an unstable aerodynamic servo loop. As the wire oscillates across the wind it generates free eddies travelling downstream such as we observe when we paddle a canoe. The detachment of the eddies changes the circulation round the wire and the circulation controls the cross wind force. We thus have a feed-back mechanism which, in this case, causes spontaneous oscillation. The mechanism is closely analogous to that of the reed in a musical instrument.

Oscillations of the structure of an airplane due to accidental aerodynamic

servo loops are known as "flutter" and have caused fatal accidents. The phenomenon has been studied both analytically and experimentally for about a quarter of a century and a number of design rules have been provided to reduce the risk as a result of which flutter incidents are now rare even on prototype aircraft. Fortunately, the relationships on which flutter depends are generally non-linear, with the result that the critical flight speed for instability is dependent on amplitude and so dependent that an increasing speed is required to sustain an increasing amplitude. Thus an experienced test pilot, on his guard against flutter, when increasing the speed of a prototype airplane above that at which he has had previous experience, can detect an incipient flutter and generally check it in time by reducing speed.

The possibility remains that a flutter could develop on a new prototype airplane in which the critical speed was reduced with increasing amplitude, in which case reduction of speed once the flutter had started might prove catastrophic. For this reason, when the possibility of flutter is suspected, the precaution is sometimes taken of deliberately shock exciting the suspected mode at progressively increasing flight speeds and recording the rate of decay so as to detect an approach to a condition of zero damping without approaching dangerously close to this condition. It may well be that some such technique will have to be adopted as a routine in all flight test programs of prototype aircraft.

The control surfaces of airplanes can provide the coupling to cause flutter. Thus, if the tail structure is oscillating from side to side the rudder will tend to move in sympathy and, under certain conditions, the resulting forces on the rudder will be phased so as to cause the main oscillation to increase. For this reason it is customary to provide mass balance in front of the hinge to counter the tendency for the control to move in response to acceleration. However, if the control surface is sufficiently rigidly located by a servo motor it may be possible to omit this balancing mass. If this argument can be substantiated the power control can be provided at little or no weight penalty because the servo motor and the balance mass are about equal in weight.

Auxiliary Controls.—I have, as I warned earlier, rather concentrated on the main applications of the art of servo mechanisms in aircraft—those involving the control of the aircraft itself. There are of course, other applications of great importance, particularly in the control of the power unit. One of the most elegant and successful of these applications is the mechanism for controlling the pitch of the airscrew to maintain constant speed of rotation with variable operating conditions of the engine. With the introduction of turbine engines, in which the temperatures are necessarily operating as close as possible to the limits set by the materials, servo mechanisms have had to be developed to regulate the fuel supply so as to control the temperature of the gases entering the turbine.

Instrumentation. — The instrumentation of the airplane, particularly the military airplane, provide numerous applications of the servo art in computation, data transmission and stabilization. We have often seen references in the war communiqués to radar-controlled bombing of unseen targets. The complexity involved in such extensions of the military arts can perhaps be appreciated from a published statement that 40 per cent of the cost of a recent American bomber is accounted for by electronic equipment, which contains no less than 1200 electronic tubes. These figures, perhaps, suggest the scope of the technological revolution to be expected when the efforts of technologists can be diverted from the needs of war to the service of man.

TESTING COMPARTMENTS FOR TIGHTNESS BY USE OF COMPRESSED AIR

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EDITOR'S NOTE

The complete article by Admiral McShane was too long for publication in a single issue of THE JOURNAL. *Parts I, II and III were published in the May 1952 issue of* THE JOURNAL; *Parts IV, V and VI appeared in the August 1952 issue and Parts VII and VIII in the November 1952 issue. The below publication of Appendices I and II completes the article.*

PART FOUR

APPENDIX I—MATHEMATICAL ANALYSIS

THE PROBLEM

The basic problem of compartment testing for tightness is to determine the total area of the apertures which exist in a given compartment. Since the area of the apertures cannot be measured directly, it must be inferred from the measurements of factors which can be determined. Preferably, the factors should be those which can be measured quickly, easily and with a minimum of apparatus, but in order to achieve reasonable accuracy it is necessary that all significant factors in the question be considered.

The compressed air which is employed in compartment testing may be considered to be a "perfect" gas. Therefore, a mathematical analysis of the phenomena can be made on the basis of the laws for "perfect" gases. However, in any practicable mathematical analysis a number of assumptions are necessary. In order that such assumptions may readily be apparent they will be printed in italics.

Description of Phenomena—In the general case a compartment under test will contain apertures through which the compressed air escapes to the atmosphere. Also, in general, the compressed air temperature will differ from the temperature of the compartment structure and the material within the boundaries. Thus, the two fundamental phenomena which occur during the period of an air test are:

(a) a decrease in the mass of the air due to leakage

(b) a change in the heat content of the air due to the dual effect of:

(1) the loss of heat due to the work of expansion

(2) heat transfer with the material which bounds the compartment and that which is within the boundaries.

These changes produce changes in the "condition" of the air remaining within the compartment and the phenomena follow the fundamental gas law:

$$pV = WRT \qquad (1)$$

where p = the instantaneous unit pressure of the air
V = the instantaneous total volume of the air
W = the instantaneous total weight of the air
R = a constant
T = the instantaneous absolute temperature of the air.

In the case of a given compartment V is constant; therefore, the changing "condition" of the air is reflected, in general, by a changing mass, pressure and temperature. If any two of these variables are determined, the third can be calculated from equation (1). The mathematical problem, then, is to obtain an expression for aperture area which is based upon the change which takes place in the mass, the pressure and the temperature of the air during the given test period.

The analysis of this problem will be divided into the following steps:

(a) an analysis of the change in the weight of the air in the compartment

(b) an analysis of the change in the temperature of the air due to the change in weight and to heat transfer

(c) using the relations developed in (a) and (b) determine the change in pressure of the air within the compartment due to the simultaneous changes in weight and temperature.

CHANGE IN WEIGHT

Expressions which give the rate of change of the weight of air in a container resulting from discharge through an orifice are found in any treatise on thermodynamics. The equations to be used depend on the ratio p/p_o where:

p = the instantaneous pressure within the container.
p_o = the back pressure into which the air escapes which in this case is the atmosphere.

When $p \geqq p_o/0.53$ $\quad dW/dt = -1908 \dfrac{cAp}{\sqrt{T}}$ (2)

When $p < p_o/0.53$ $\quad dW/dt = -7380 \dfrac{cAp_o}{\sqrt{T}} \sqrt{\left(\dfrac{p}{p_o}\right)^{\frac{k-1}{k}} \left[\left(\dfrac{p}{p_o}\right)^{\frac{k-1}{k}} - 1\right]}$ (3)

Where dW/dt = change in the weight of air in the container in lbs. per *hour*
c = the coefficient of discharge through the aperture, a constant
A = area of the aperture in *sq. ft.*
p and p_o = *absolute* pressures in lbs. per *sq. ft.*
k = the "index" of expansion in the aperture, a constant

Note that in this problem, where air always escapes from the compartment, the value of dW/dt always is negative. For practical reasons the following assumptions (which will not introduce significant errors) will be made:

(a) *that p_o always is 14.7 lbs. per sq. in.*

(b) *that the expansion in the apertures is adiabatic,* hence $k = 1.4$ and $(k-1)/k = a = 0.286$

(c) *That T remains constant.* For the usual conditions in air tests dW/dt will not be affected sensibly by the changes taking place in T.

With these assumptions the variables in equations (2) and (3) are W, t and p. Then equations (2) and (3) may both be expressed:

$$dW/dt = -bf(p)cA \tag{4}$$

where $b = 1908/T^{1/2}$ or $7380p_o/T^{1/2}$

and $f(p) = p$ or $\left\{ (p/p_o)^a \left[(p/p_o)^a - 1 \right] \right\}^{1/2}$

depending on the value of (p/p_o).

For this analysis it is necessary that dW/dt be expressed in terms of W rather than p. From equation (1)

$$p = (R/V)\ WT$$

Substituting this in equations (2) and (3) give

$$dW/dt = -(bRT/V)\ cAW \tag{5}$$

and $dW/dt = -[7380\ (RT/V)^{a/2}\ (p_o^{1-a}/T^{1/2})]$

$$cA \left\{ W^a [(RT/V)^a W^a - p_o^a] \right\}^{1/2} \tag{6}$$

Both equations (5) and (6) may be expressed for convenience

$$dW/dt = -KcAf(W) \tag{7}$$

where the values of K and $f(W)$ are apparent.

In order to obtain an expression for W in terms of constants and t it is necessary to integrate equations (5) and (6). The integral of (5) is

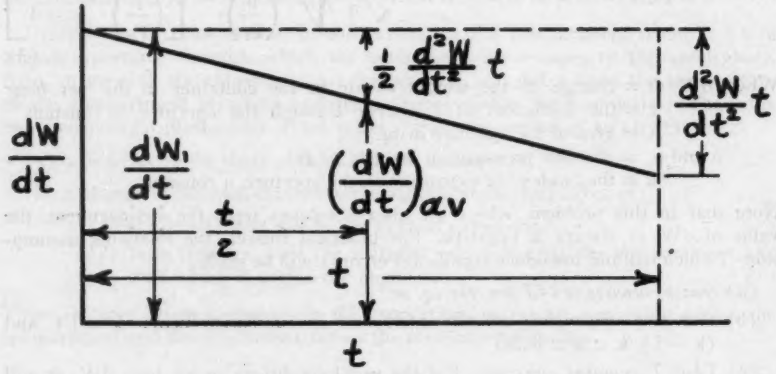
$$\log W = -KcAt + C$$

when $t = 0$, $W = W_1$ hence

$$\log W = -KcAt + \log W_1$$

or $W = W_1 e^{-KcAt}$ (8)

where e is the base of natural logarithms. Equation (6), however, is not directly integrable and the following scheme of integration is adopted. For the usual values of t encountered in compartment testing a plot of dW/dt versus t will



be essentially a straight line, i.e., d^2W/dt^2 is constant. The equation of this line is

$$\frac{dW}{dt} = \frac{dW_1}{dt} + \frac{1}{2}\frac{d^2W_1}{dt^2}t \tag{9}$$

Where dW_1/dt and d^2W_1/dt^2 are the values *at the start of the* test, i.e., where $t = 0$. This being the case, the *average* value of dW/dt for the duration of the test is

$$\left(\frac{dW}{dt}\right)_{av} = \frac{dW_1}{dt} + \frac{t}{2}\frac{d^2W_1}{dt^2} = w \tag{10}$$

and, consequently

$$\int \frac{dW}{dt}\,dt = \left(\frac{dW}{dt}\right)_{av} t = wt \tag{11}$$

The value of wt represents the loss in weight of air in the time t and

$$W = W_1 + wt \tag{12}$$

The problem becomes one of finding a usable expression for d^2W_1/dt^2.

Differentiating equation (6) gives

$$d^2W/dt^2 = (KcA)^2(a/2W)\left\{(RT/V)W^{2a} + W^a[(RT/V)W^a - p_o^a]\right\} \tag{13}$$

Now make the substitution $W = pV/RT$

$$d^2W/dt^2 = (bcA)^2\, f(p)(RT/V)(a/2p)\left\{f(p) + [1/f(p)]\ (p/p_o)^{2a}\right\} \tag{14}$$

If
$$(a/2p)\left\{f(p) + [1/f(p)](p/p_o)^{2a}\right\} = F(p) \tag{14a}$$

equation (14) may be written

$$d^2W/dt^2 = (dW/dt)\ b\ (cA/V)\ RT\ F(p) \tag{15}$$

The numerical value of d^2W/dt^2 may be positive if the pressure in the compartment is rising due to sufficient transfer of heat or negative if the pressure is falling. Because the usual condition encountered in practice is a falling pressure, *it will be assumed that d^2W/dt^2 always is negative.* Now substituting equations (4) and (15) in equation (11), noting that it is the values of dW/dt and d^2W/dt^2 at the *start* of the test which are employed

$$w = -b\ f(p_1)cA\ [1 - (\tfrac{1}{2})bRT_1\ F(p_1)(cA/V)t] \tag{16}$$

Now because they are constants for a given *initial* pressure p_1 let

$$bf(p_1) = B$$
$$(\tfrac{1}{2})bRT_1\ F(p_1) = E$$

and equation (16) may be written

$$w = -BcA[1 - E\ (cA/V)t] \tag{17}$$

whence $$W = W_1 - BcAt[1 - E\ (cA/V)t] \tag{18}$$

In summary, we have

If $p \geqq p_0/0.53$ $\qquad W = W_1 e^{-(bRT_1)(cA/V)t}$ (7)

If $p < p_0/0.53$ $\qquad W = W_1 - BcAt[1 - E\ (cA/V)t]$ (18)

where $b = 1908/T^{1/2}$
$B = bf(p_1)$
$E = (\tfrac{1}{2})\ bRT_1\ F(p_1)$

CHANGE IN TEMPERATURE

As air leaks from the compartment through the apertures the temperature of the air which remains within the compartment tends to decrease as a result of the expansion which takes place. The compartment boundaries and the material within the boundaries do not remain at a constant temperature but change as a result of fluctuations in ambient temperature, solar radiation and due to the presence of welding arcs, rivet heaters, steam coils, etc. Thus, temperature differences between the boundaries and the air within the compartment are set up. The general case in a compartment test will be:

(a) at the start of the test the temperature of the air within the compartment differs from that of the boundaries

(b) during the progress of the test the boundary temperature undergoes a change

The problem is to determine the change in air temperature under this condition.

Basic Assumptions—In order to procure a mathematical solution the following basic assumptions will be made, none of which should be disastrous to the accuracy of the solution:

(a) *that the change in boundary temperature is a linear function of time.* For the usual periods of air tests this should be quite close to the actual conditions.

(b) *that the heat extracted from or added to the boundaries will have no effect on their temperature.* This, of course, is implied by the preceding assumption but is stated here to avoid misunderstanding. The boundaries of a given compartment are really a small part of the great reservoir of heat

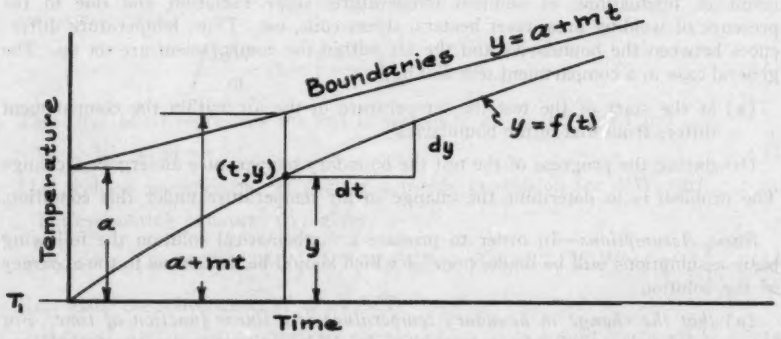
represented by the entire ship's structure and their temperature is not likely to be affected measurably by the relatively small quantity of heat added to or extracted from the compressed air in the compartment.

(c) *that the initial boundary temperature and the change in boundary temperature in a given period of time is the same at all parts of the boundary.* This, very likely, is not true but the variations probably are not sufficient to create great errors.

(d) *that the heat transfer takes place wholly from the bulkhead and deck plating.* This definitely is not the case. Beams, stiffeners, installed material, etc., which are inside the plate boundaries all serve to transmit heat. The assumption that they do not, may, in certain instances, give rise to large errors but the actual conditions are too variable to encompass within a practicable solution. On the average this assumption should not be a major disturbance.

(e) *that the temperature of the compressed air will be the same in all parts of the compartment.* This is not true. The temperature near the overhead probably will be greater than near the deck. However, this fact must be neglected and the temperature assumed or calculated must represent average conditions.

Solution—The assumed conditions are represented in the following diagram. The origin of abscissae is the start of the test, i.e., time is zero. The origin of ordinates is the initial temperature of the air within the compartment, T_1. The initial temperature difference between the air and the boundaries is "a" and the boundary temperature follows the line $y = a + m\ t$. As air escapes through the apertures and as heat transfer occurs, the temperature of the air remaining within the compartment follows the curve $y = f(t)$, the equation of which is to be determined.



At the point (t,y) the air is changing its temperature by the amount dy in the time interval dt. At that point the instantaneous weight is W and the weight is changing at the rate dW/dt. A fundamental equation for expanding gases states that *for each pound* of gas the heat which must be added to (or subtracted from) the surroundings is:

$$dq = c_p dT - (v/J)\ dp$$

where c_p = specific heat at constant pressure

v = cu. ft. *per lb.*

J = the mechanical equivalent of heat, i.e., 778 ft.lb. per b.t.u.

For a total weight of W lbs., the total added heat must be

$$Wdq = Wc_p dT - (Wv/J)\ dp$$

Now $Wdq = dQ$ the total added heat

$Wv = V$ the constant volume of the compartment,

hence: $$dQ = Wc_p dT - (V/J)\ dp \qquad (19)$$

Differentiating equation (1) gives

$$dp = (R/V)(WdT + TdW)$$

Substituting this in equation (19) gives

$$dQ = W(c_p - R/J)dT - (R/J)TdW$$

Now $c_p - R/J = c_v$ the specific heat at constant volume and, according to the notation adopted here, $dT = dy$ and $T = T_1 + y$. Hence:

$$dQ = Wc_v dy - (R/J)(T_1 + y)\ dW \qquad (20)$$

This equation may be translated thus: if, starting at the point (t, y) where the weight of air is W and its absolute temperature is $(T_1 + y)$, the loss of air is dW and the simultaneous addition (or subtraction) of heat from the surroundings is dQ, then the temperature of the air will change by the amount dy.

The source of added heat is the compartment boundaries; the potential which creates the heat transfer is the temperature difference $[(a + mt) - y]$ and thus the amount of heat transferred to the air in the time dt is:

$$dQ = hS\ (a + mt - y)\ dt \qquad (21)$$

where h = the coefficient of heat transfer. This coefficient is dependent on $(a + mt - y)$. Its value at the low temperature differences involved in this problem is not well defined. *In this analysis h will be assumed constant.*

S = the area of the boundaries in sq. ft.

Equating (20) and (21) and rearranging

$$a + mt - y = (c_v/hS)\ W\ (dy/dt) - (R/hSJ)\ (T_1 + y)\ (dW/dt) \qquad (22)$$

In equation (17) the value of $E(cA/V)t$ usually is small enough to be negligible in which case $w = (dW/dt) = -BcA$ *may be assumed constant.* Likewise, in equation (2) it may be assumed for the purpose at hand *that dW/dt is constant.* Therefore, we may say

$$dW/dt = w = -BcA$$
$$W = W_1 + wt = W_1 - BcAt$$

For further simplification let the following constants be

$$c_v/hS = G$$
$$R/hSJ = H$$
$$a + wHT_1 = M$$

Then equation (22) may be written

$$\frac{dy}{dt} + \frac{(1 - wH)}{G(W_1 + wt)} y = \frac{M - mt}{G(W_1 + wt)} \qquad (23)$$

This is a "linear" equation, the general solution of which is:

$$y = \frac{1}{1 - wH}\left[M + m\left(\frac{t - GW_1 - wHt}{1 + wG - wH}\right) + (W_1 + wt)^{-(1-wH)/wG} C \right]$$

For the specific case here $y = 0$ when $t = 0$. Thus,

$$C = \left[1/(1 - wH)\ W^{-(1-wH)/wG} \left(M - \frac{mGW_1}{1 + wG - wH} \right) \right]$$

Substituting this value and replacing M by its value $(a + wHT_1)$ gives:

$$y = \frac{1}{1 - wH}\left(a + wHT_1 - \frac{mGW_1}{1 + wG - wH}\right)$$
$$\left[1 - \left(1 + \frac{wT_1}{W_1}\right)^{-} (1 - wH)\ /wG\right] + \frac{mt}{1 + wG - wH} \qquad (24)$$

Within the limitations of the assumptions made this is an exact equation but for practical purposes *the following simplifications may be adopted:*

(a) w has such a small value that the expressions $(1 - wH)$ and $(1 + wG - wH)$ may be taken to be unity with a negligible error.

(b) as w approaches zero as a limit, the expression

$$(1 + wT/W_1)^{-(1-wH)/wG}$$

approaches as a limit the value e^{-t/GW_1} where e is the base of natural logarithms. This latter expression is simpler to use and for the purposes in hand is satisfactory.

Thus, equation (24) may be expressed:

$$y = (a + wHT_1 - mGW_1)\ (1 - e^{-t/GW_1}) + mt$$

or, rearranging it,

$$y = (1 - e^{-t/GW_1})\ (a + wHT_1) + \left[1 - \frac{(1 - e^{-t/GW_1})}{t/GW_1}\right] mt \qquad (25)$$

Now translate wHT_1 and t/GW_1 into terms which can safely be assumed or readily measured.

(a) $w = -BcA = -bf(p)cA$
$H = R/hSJ$
so, $wHt_1 = -[(BRT_1)/(hSJ)]\ cA/S$

(b) $G = c_v/hS$
$W_1 = p_1V/RT_1$
so, $t/GW_1 = [(hRT_1)/(c_vp_1)]\ tS/V$

So far all areas have been expressed in *sq. ft.*, all pressures in lbs. per *sq. ft.*, and all times in *hours*. For practical use it is preferable to express

(a) cA in sq. ins. Hence, wherever cA appears it must be divided by 144.

(b) pressures in lbs. per sq. in. Hence, wherever p appears it must be multiplied by 144. Note, however, that pressure *ratios* are dimensionless.

(c) times in minutes. Hence, wherever t, w, b or B appear they must be divided by 60.

The various constants employed so far have the following values:

(a) *It is assumed in all calculations that the relative humidity is 50%.* In this case R = 53.44.

(b) The value of T_1, the *initial* air temperature, will in practice vary over a quite wide range. However, for all calculative purposes *it will be assumed to be 520°.* Investigation will show that the error thus introduced is negligible for practical purposes.

(c) J is 778 ft.lbs. per b.t.u.

(d) c_v for air is 0.171.

(e) The value of "h" for very low temperature differences is not well defined. It has been assumed to be constant and the values to be employed will be discussed later.

Then, for the following units:

p_1 in lbs. per sq. in.
p_o at 14.7 lbs. per sq. in.
cA in sq. ins.
S in sq. ft.
V in cu. ft.
t in minutes.

when $p_1 \geqq 14.7/0.53 = 27.8$ $\quad w = -bf(p_1)cA = \dfrac{1908}{60\sqrt{520}} \times 144\ p_1 \dfrac{cA}{144}$

$= 1.395\ p_1 cA$. Hence, $B = 1.395 p_1$

$p_1 < 27.8$

$$w = -bf(p_1)cA = -\frac{7380 \times 144 \times 14.7}{60\sqrt{520}} f(p_1) \frac{cA}{144} = -79.3 f(p_1) cA$$

Hence, $B = 79.3\ f(p_1)$

$$wHT_1 = \frac{(BcA)}{hS} \frac{RT_1}{J} = -\frac{(BcA)}{hS} \cdot \frac{53.44 \times 520}{778} \times 60$$

$$= -2145.2B \frac{1}{h} \frac{cA}{S} = -\frac{F}{h} \frac{cA}{S}$$

Where F = 2145.2 B and B has values given above.

$$\frac{t}{GW_1} = \frac{RT_1}{c_v p_1} ht \frac{S}{V} = \frac{53.44 \times 520}{0.171 \times 144 p_1} h \frac{t}{60} \frac{S}{V} = \frac{18.855}{p_1} ht \frac{S}{V} = Kht \frac{S}{V}$$

Where $K = 18.855/p_1$

It will be noted that B, F and K are functions only of p_1, the *initial* absolute pressure, i.e., the "test pressure." Appropriate values are given in Table II.

For further convenience let

$$KhtS/V = L$$
$$(1 - e^{-L}) = N$$
$$1 - N/L = P$$

Then equation (25) may be written

$$y = N[a - (F/h)\ (cA/S)] + Pmt \qquad (26)$$

N and P are functions of L which, in turn, depends on $(18.855/P_1)$ htS/V. Appropriate values of N and P are given in Table III. Equation (26) may be

written

$$y = (Na + Pmt) - NF\ (1/h)\ cA/S \qquad (26a)$$

The expression $(Na + Pmt)$ depicts the effect of the boundary temperatures on the air temperature; the expression $- NF\ (1/h)\ cA/S$ depicts the effect of leakage through the apertures. It is interesting to note that only when

$$Na + Pmt = NF(1/h)\ cA/S$$

will the temperature of the air remain constant.

The value of y is dependent on the following factors:

p_1 the test pressure.
t the period of the test.
S the area of the boundaries.
V the compartment volume.
cA the effective aperture area.
a the initial temperature difference.
m the rate of change of boundary temperature.

All of these factors are constant *for a given test* but for all of the tests which are conducted each factor covers a wide range. Because of this range and the variety of combinations which is encountered in practice, it may be expected that y will vary widely.

Since the values of N and P depend in part upon the ratio S/V the characteristics of this ratio are of interest. For a rectilinear compartment

$$S/V = 2(L_1L_2 + L_1L_3 + L_2L_3)/L_1L_2L_3 = (2/L_1) + (2/L_2) + (2/L_3) \qquad (27)$$

where L_1, L_2 and L_3 are the dimensions of the compartment. Even in the cases of compartments which depart considerably from rectlinear form equation (27) gives a quite good approximation of S/V if *average* values of the principal dimensions are used. Since the ratio is dependent on twice the sum of the reciprocals, its value cannot be less than twice the reciprocal of the smallest dimension. Further, the smaller the value of the minimum dimension, the greater the value of S/V. Thus, the rapidity of heat transfer depends to a large degree on the specific value of the *minimum* dimension. For example, a space with dimensions $8' \times 8' \times 8'$ has an S/V of 0.75 and a volume of 512 cu. ft. A compartment with dimensions $4' \times 8' \times 16'$ having the same volume has an S/V of 0.875, and a compartment $3' \times 16' \times 24'$ with about twice the volume (1152 cu. ft.) has the same ratio, 0.875. Consequently, it may be expected that the most "sensitive" compartments are those with small volumes or those with larger volumes but with small minimum dimensions.

The value of h is an important factor which must be evaluated. Mark's Handbook (1916 edition) gives for air at rest

$$h = 0.62 + 0.009\ y.$$

as applying to values of $y < 20°$ F. Later investigations as reported in Mark's Handbook (1941 edition) gives for natural convection

$$h = g\ (a + mt - y)^{0.25}$$

where $g = 0.3$ for vertical plates more than 3 ft. high.
$g = 0.38$ for horizontal plates facing upward.
$g = 0.2$ for horizontal plates facing downward.

Using these various relations, and assuming that values of y and $(a + mt - y)$ will not exceed about 0.5° F, the values of h would be

$(a + mt - y)$	Mark's, 1916	Mark's, 1941		
		g = 0.3	0.38	0.2
0.1	0.62	0.17	0.21	0.11
0.2	.62	.19	.24	.13
0.3	.62	.22	.28	.15
0.4	.62	.24	.30	.16
0.5	.62	.25	.32	.17

A very crude check of the order of magnitude of h is afforded by tests on the *Albemarle* which are described in the text. In these tests a compartment was filled with air at 2 p.s.i. gage and temperatures of the boundary and of the compressed air were measured. The tests are not too good for the following reasons:

(a) the thermometers could not be read with great precision and were "sluggish."

(b) the boundary temperature was measured at only one point.

(c) there was an observer within the compartment whose body heat retarded the drops in air temperature. This factor would serve to indicate a lower value of h than otherwise would have existed.

The compartment tested was apparently practically "bottle-tight." Thus, equation (26) would be

$$y = Na + Pmt$$

By assuming a value of $h = 0.23$ the theoretical change in temperature can be calculated which shows quite good correlation with the observed values. On the basis of these data it seems quite conservative *to assume an average value of* $h = 0.2$ b.t.u./sq.ft./°F/hr. This value will be used in all calculations.

With all the variety which seems possible in the temperature variations in practical air tests, it remains to be seen whether these variations are significant.

CHANGE IN PRESSURE

For purposes of this analysis a "drop" in pressure will be considered positive. From equation (1)

$$p_1 = (R/V)\ W_1T_1 \text{ and } p = (R/V)\ WT$$

If the "drop" in pressure be denoted by d

$$d = p_1 - p = (R/V)\ (W_1T_1 - WT) = (R/V)[W_1T_1 - (W_1 + wt)(T_1 + y)]$$
$$= (R/V)\ (-w\ t\ T_1 - W_1y - wty)$$

Substituting equation (17) for w

$$d = BRT_1(cA/V)\ t\ [1 - E\ (cA/V)t]\ [1 + (y/T_1)] - (p_1/T_1)y \qquad (28)$$

The expression (y/T_1) *is negligible for all practical purposes.* Further, it is desirable to express d in ounces per sq. in. rather than in lbs. per sq. in., so equation (28) should be multiplied by 16, whence

$$d = 16\ BRT_1(ca/V)t\ [1 - E(cA/V)t] - 16\ (p_1/T_1)\ y$$

Now let $16\ BRT_1 = D$ and $16\ (p_1/T_1) = Q$

$$d = D\ (cA/V)t\ [1 - E\ (cA/V)t] - Qy \qquad (29)$$

where D, E and Q are functions solely of the test pressure p_1. Appropriate values are given in Table II.

It will be noted that equation (29) introduces no factors additional to those on which y is dependent as tabulated on page 155 and, thus, the values of d will depend on those factors. In a given case the ratio cA/V and the test pressure p_1, are fixed quantities. The important consideration, therefore, is whether the value of Qy will affect d significantly in practice. Consequently, representative calculations are made below to indicate the extremes of the conditions which appear likely to be encountered. The following are postulated as conservative representations of extremes:

(a) a small compartment 8′ × 8′ × 8′ having a high S/V of 0.75

(b) a large compartment 16′ × 24′ × 60′ having a low S/V of 0.2415

(c) the cA/V *ratio* selected is the same for both compartments to provide a reasonable basis for comparison of temperature effects. The value of this ratio is not unusual as evidenced by the values of pressure drop.

(d) three test pressures are selected, viz 1 lb./sq. in. and 4 lbs./sq. in to represent the range in which "completion" tests are conducted and 10 lbs./sq. in. to represent high "strength and tightness" test pressures. (The pressures are stated in *gage* values, not absolute values.)

(e) in all cases the extremes of boundary temperature conditions which have been selected are:

$$a = \pm 0.2°F,\ m = \pm 0.02°F \text{ per minute}$$

These figures do not seem unreasonable as representations of actual phenomena.

Small Compartment, Small Aperture.

Dimensions 8′ × 8′ × 8′ $\qquad p_1 = 1$ p.s.i. gage

$cA = 0.26 \times 10^{-3}$ sq. ins.

$cA/S = 0.0678 \times 10^{-5} \qquad F = 23.4 \times 10^{3} \qquad (F/h)(cA/S) = 0.0792$

$cA/V = 0.508 \times 10^{-6} \qquad D = 31.9 \times 10^{3} \qquad DcA/V = 0.01621$

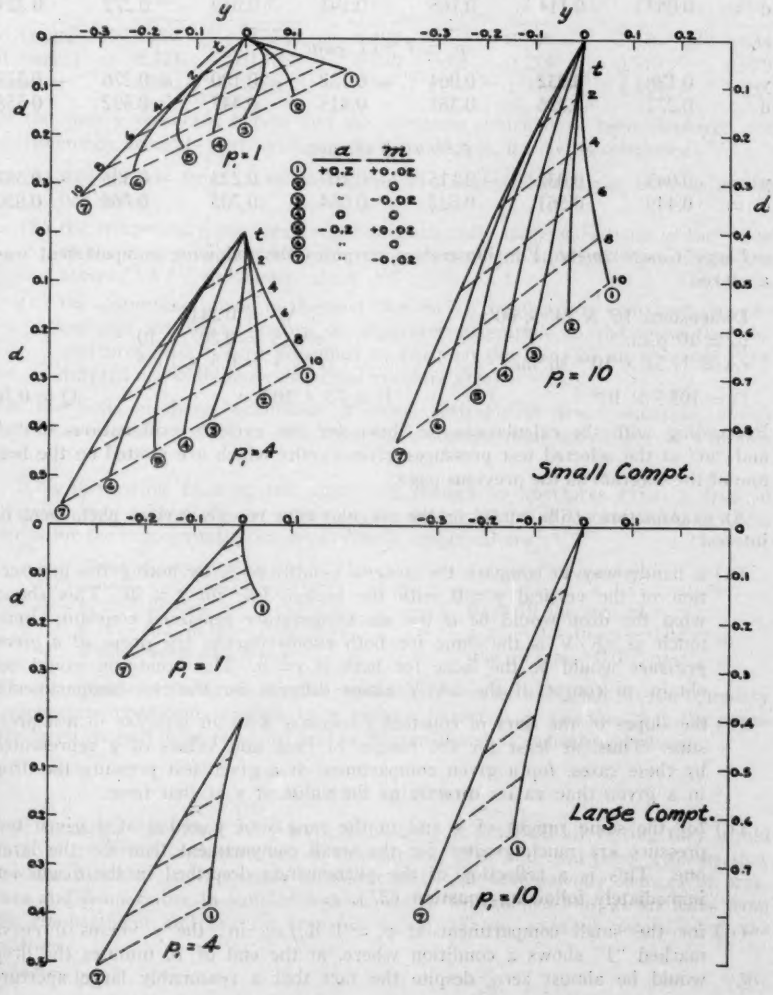
$S/V = 0.75 \qquad Q = 0.482$

$$y = Na + Pmt - N(F/h)(cA/S)$$
$$d = D(cA/V)t - Qy$$

t	*2*	*4*	*6*	*8*	*10*
N	.300	.501	.649	.759	.822
P	.159	.280	.382	.462	.529
Pt	.318	1.120	2.292	3.696	5.290
0.2 N	.060	.100	.130	.152	.164
0.02 Pt	.006	.022	.046	.074	.106
$-N(F/h)(cA/S)$	−.024	−.040	−.051	−.060	−.065
$D(cA/V)t$	.032	.065	.097	.130	.162

t	2	4	6	8	10
	$a = +0.2,\ m = +0.02$				
y	.042	.082	.125	.166	.205
— Qy	— .020	— .040	— .060	— .080	— .099
d	.012	.025	.037	.050	.063

Similar calculations for other values of "a" and "m" give results which are plotted on the top part of the below diagram.



Similar sets of calculations have been made for values of p_1 of 4 and 10 p.s.i. gage and the results are also plotted in this diagram.

The conditions *at the end of 10 minutes* are summarized below.

a =	+ 0.2	+ 0.2	+ 0.2	0	− 0.2	− 0.2	− 0.2
m =	+ 0.02	0	− 0.02	0	+ 0.02	0	− 0.02
			p_1 = 1 p.s.i. gage				
y =	0.205	0.099	− 0.007	− 0.065	− 0.123	− 0.229	− 0.335
d =	0.063	0.114	0.165	0.193	0.059	0.272	0.324
			p_1 = 4 p.s.i. gage				
y =	0.128	0.032	− 0.064	− 0.122	− 0.180	− 0.276	− 0.372
d =	0.271	0.326	0.381	0.415	0.447	0.502	0.558
			p_1 = 10 p.s.i. gage				
y =	0.049	− 0.033	− 0.115	−0.169	− 0.223	− 0.305	− 0.387
d =	0.449	0.561	0.623	0.664	0.705	0.768	0.830

Large Compartment. For illustrative purposes the following compartment was analyzed

Dimensions $16' \times 24' \times 60'$ $\quad S/V = 0.2415$

$p_1 = 10$ p.s.i. $\quad cA/S = 0.207 \times 10^{-5}$

$cA = 11.52 \times 10^{-3}$ sq. ins. $\quad cA/V = 0.5 \times 10^{-6}$

$D = 105.5 \times 10^3$ $\quad F = 73 \times 10^3$ $\quad Q = 0.76$

Proceeding with the calculations as above for the various combinations of "a" and "m" at the selected test pressures gives results which are plotted on the bottom of the diagram on the previous page.

An examination of the curves on the previous page reveals various phenomena of interest:

(a) a handy way to compare the *general* conditions is by noting the intersection of the vertical $y = 0$ with the broken line for $t = 10$. This shows what the drop would be *if* the air temperature remained constant. Inasmuch as cA/V is the same for both compartments, the drops *at a given pressure* would be the same for both if $y = 0$. This condition would not obtain, of course, if the cA/V ratios differed for the two compartments.

(b) the slopes of the lines of constant t increase with an increase in test pressure. Thus, at least for the ranges of time and values of y represented by these cases, for a given compartment at a given test pressure the drop in a given time varies directly as the value of y at that time.

(c) for the same ranges of a and m the ranges of y and d at a given test pressure are much greater for the small compartment than for the large one. This is a reflection of the phenomenon described in the discussion immediately following equation (27).

(d) for the small compartment at $p_1 = 1$ lb./sq. in., the y versus d curve marked "1" shows a condition where, at the end of 10 minutes the drop would be almost zero, despite the fact that a reasonably large aperture

existed and air had escaped. This situation may explain many of the "zero" drops recorded in the past. In other words, a "zero" drop may not necessarily indicate that the compartment is "bottle-tight."

(e) the phenomenon of chief significance is that for a given compartment tested at a given pressure the value of d varies markedly with quite small variations in boundary temperature conditions. The following table summarizes the minimum and maximum drops at the end of 10 minutes

	Small Compartment			*Large Compartment*		
$p_1 =$	*1*	*4*	*10*	*1*	*4*	*10*
d (min)	0.063	0.271	0.499	0.146	0.376	0.634
d (max)	0.324	0.558	0.830	0.278	0.510	0.779
ratio	5.14	2.06	1.66	1.90	1.36	1.23

If the theory presented herein and the constants which have been employed are satisfactorily accurate portrayals of actual conditions, it may be concluded:

(a) that the air temperature at the end of a test seldom is the same as at the beginning.

(b) the temperature changes produce significantly large variations in the value of the drop and, therefore, the drop alone is an unreliable measure of the ratio of cA/V and, hence, of cA.

(c) the assumption made in the past that the air temperature remained sensibly constant introduced errors of important magnitude in the sense that the apertures which were presumed to exist on the basis of an observed drop differed markedly from the actual aperture areas.

On the basis of these conclusions it seems desirable to devise equations which take into account the effect of temperature changes and which are in a usable form.

It is interesting to note, too, that even though no apertures exist, a drop in pressure may take place due solely to the heat transfer. The magnitude of these drops for the representative cases previously employed are:

Small Compartment	*Large Comparment*
$p_1 = 1$ lb./sq. in.	$p_1 = 10$ lbs./sq. in.
$a = -0.2$, $m = -0.02$	$a = -0.2$, $m = -0.02$
d in 10 mins., 0.130 ozs.	d in 10 mins., 0.072 ozs.

The magnitude of the drops for the representative cases are small. If the boundary temperature conditions change to a greater extent it is possible that the drops are large enough to be recorded and to be considered as indicating leakage.

MODIFIED EQUATIONS

If equations (26) and (29) were to be used in practical air testing they would entail a relatively awkward set of calculations. For this and other reasons they are not suitable. It is possible to characterize the simultaneous changes of pressure and temperature in simpler fashion. *Let it be assumed that,* as air leaks from the compartment and as heat transfer occurs, *the air expands according to the relation*

$$pv^n = p_1 v_1^n \qquad (30)$$

where n is constant. Then, since $v = V/W$ and $v_1 = V/W_1$

$$p = p_1 (W/W_1)^n = p_1 [(W_1 + wt)/W_1]^n$$

and $$d = p_1 - p = p_1 \{ 1 - [1 + (wt/W_1)]^n \} \quad (31)$$

Now $$[1 + (wt/W_1)]^n = 1 + nwt/W_1 + (n/2)(n+1)(wt/W_1)^2 + \text{----}$$

The terms containing $(wt/W_1)^2$ and higher powers are negligible, so

$$d = p_1 (-nwt/W_1)$$

Substituting equation (17)

$$d = (p_1/W_1) \text{ BncAt } [1 - E (cA/V)t]$$

Since $W_1 = p_1 V/RT_1$

$$d = BRT_1 n (cA/V)t [1 - E (cA/V)t]$$
$$= Dn (cA/V)t [1 - E (cA/V)t] \quad (32)$$

Equation (32) may be written

$$n = d/D(cA/V)t [1 - E (cA/V)t] \quad (32a)$$

The significance of equations (32) and (32a) is that *if* the air had expanded according to $pv^n = p_1 v_1^n$ the drop at the end of t minutes would have been d. It should be noted that a single value of n does not actually exist during a given test. For instance, take the conditions which obtained in the "small" compartment example when $p = 1$, $a = +0.2$ and $m = -0.02$. The values of n at various time intervals would be

t	*2*	*4*	*6*	*8*	*10*
d	−.016	.013	.057	.106	.156
D(cA/V)t*	.032	.065	.097	.130	.162
n	−.50	.20	.59	.82	.96

* E(cA/V)t is negligible

It is usual, however, that interest is centered only on the conditions at the end of a test, so equations (32) and (32a) are satisfactory for such practical use and the value of n indicates the effect of heat transfer.

Graphic methods of solution. Equation (32) is susceptible of graphic solution by several methods. This—a fact, unfortunately, too seldom recognized in many similar cases—eliminates most of the labor where many calculations must be made. Equation (32) may be written

$$d/n = D(cA/V)t [1 - E(cA/V)t] \quad (32b)$$

Thus, d/n is a function of p_1 and $(cA/V)t$. A series of curves plotted on arithmetic coordinates with d/n and p_1 as arguments will solve the problem. A representative set of calculations is as follows:

(a) At $p_1 = 16$ lbs. per sq. in. gage. Take values of D and E from Table II.

$tcA/V = 10 \times 10^{-6}$, $d/n = 0.1325 \times 10 [1 - 0.00014 \times 10] = 1.323$

$tcA/V = 80 \times 10^{-6}$, $d/n = 0.1325 \times 80 [1 - 0.00014 \times 80] = 10.481$

(b) At $p_1 = \frac{1}{4}$ lb. per sq. in. gage.

$tcA/V = 10 \times 10^{-6}$, $d/n = 0.0169 \times 10 [1 - 0.00108 \times 10] = 0.167$

$tcA/V = 100 \times 10^{-6}$, $d/n = 0.0169 \times 100 [1 - 0.00108 \times 100] = 1.507$

The "Table A" which follows has been calculated in this fashion and the "Air Test Curves," which also follow, are constructed from the data in this table. It

TABLE A

The body of the table gives values of (d/n) as calculated from:

$$(d/n) = D(cA/V)t\ [1 - E(cA/V)t]$$

p (Gage) lbs.	$t\frac{cA}{V} \times 10^6$ (t in mins., A in sq. ins., V in cu. ft.)														
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
16	1.32	2.64	3.96	5.27	6.58	7.88	9.19	10.49							
12	1.15	2.30	3.44	4.58	5.73	6.86	7.99	9.12	10.24	11.36					
8	.95	1.89	2.83	3.77	4.70	5.63	6.56	7.48	8.41	9.32	10.23				
6	.82	1.64	2.46	3.28	4.09	4.89	5.70	6.50	7.29	8.08	8.89	9.66	10.43		
4	.68	1.35	2.02	2.68	3.35	4.00	4.66	5.31	5.96	6.60	7.24	7.88	8.52	9.15	9.76
3	.59	1.17	1.75	2.32	2.90	3.46	4.03	4.59	5.15	5.70	6.25	6.79	7.34	7.88	8.42
2	.48	.96	1.43	1.90	2.37	2.83	3.29	3.75	4.20	4.65	5.09	5.53	5.96	6.41	6.84
1½	.41	.82	1.23	1.64	2.04	2.43	2.82	3.21	3.60	3.98	4.36	4.73	5.09	5.46	5.83
1	.33	.67	1.00	1.33	1.65	1.97	2.28	2.59	2.91	3.21	3.51	3.80	4.09	4.38	4.68
½	.24	.48	.71	.94	1.17	1.39	1.61	1.82	2.03	2.24	2.45	2.65	2.84	3.04	3.22
¼	.17	.33	.49	.65	.81	.95	1.10	1.24	1.38	1.51	1.65	1.78	1.90	2.01	2.13

will be noted that the curves are straight lines at the higher pressures but as the pressures decrease the curves become increasingly convex. In other words, at the higher pressures E(cA/V)t is negligible but becomes increasingly significant as the test pressure decreases. Thus, at higher pressures it is practically satisfactory to say

$$d/n = D(cA/V)t \tag{33}$$

but at lower pressures this equation does not give a desirable degree of accuracy.

If the curves be plotted on logarithmic coordinates, the result is a series of straight lines of varying slopes. This indicates that the equation

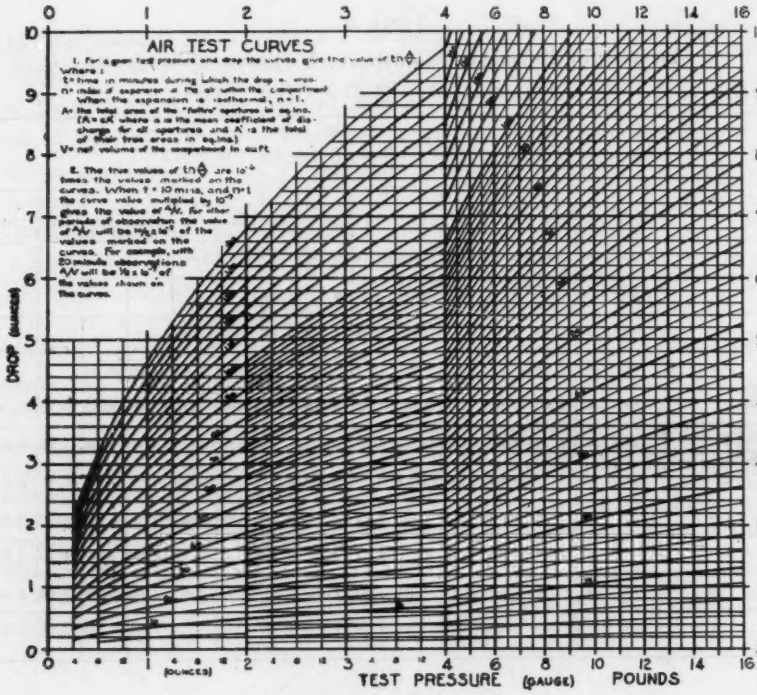
$$(d/n) = [M\ (cA/V)t]^a \tag{34}$$

will portray the conditions with satisfactory accuracy. The value of a, which determines the slope on logarithmic coordinates, varies from 0.99 at $p_1 = 16$ lbs. per sq. in. to about 0.94 at ¼ lb. per sq. in. A family of parallel straight lines with slope of 0.984 and intersecting the original lines where the latter intersect the line $d/n = 2.0$ are a satisfactory substitute. This permits the conditions to be represented by:

$$(d/n) = [M(cA/V)t]^{0.984} \tag{35}$$

or

$$\frac{(d/n)^{1.0163}}{t} = M(cA/V) \tag{35a}$$



This is a form which is suitable for solution by a relatively simple chart or, more conveniently for repetitive calculations, by slide rule. The values of M may be found by substituting appropriate values of (d/n) and t(cA/V) from Table A by selecting values when d/n is about 2.0. For instance, at 4 p.s.i. gage.

$d/n = 2.02$ when $t\ (cA/V) = 30 \times 10^{-6}$

$2.02^{1.0163} = M \times 30 \times 10^{-6}$, $M = 0.0681 \times 10^{6}$

Values of M at various values of p_1 are:

p_1	$M \times 10^{-6}$	p_1	$M \times 10^{-6}$	p_1	$M \times 10^{-6}$
¼	0.0145	2	0.0480	8	0.0955
½	.0228	3	.0588	12	.1165
1	.0332	4	.0681	16	.1341
1½	.0413	6	.0832		

Logarithmic Chart—If equation (35a) is written

$$M\ (cA/V) = X = \frac{(d/n)^{1.0163}}{t}$$

it may be broken into two parts, thus:

$cA/V = X/M$ and $(d/n)^{1.0163} = tX$

By taking logs of both sides:

$$\log cA - \log V = \log X - \log M \qquad (35b)$$

$$1.0163 \log d - 1.0163 \log n = \log t + \log X \qquad (35c)$$

Each of these equations defines a chart, one to solve each equation. If these charts are placed side by side with the axes for "X" coinciding, the result is a graphical solution.

Slide rule—Equation (35a) may be transformed into:

$$\frac{cA}{V} M\ t\ n^{1.0163} = d^{1.0163}$$

By taking logs of both sides.

$$\log cA - \log V + \log M + 1.0163 \log n + \log t = 1.0163 \log d \qquad (35d)$$

For certain reasons, explained later, it is simpler to consider *alternate* subtractions and additions of logs to transform (35d) into:

$$\log cA - \log V + \log M - 1.0163 \log (1/n) + \log t = 1.0163 \log d \qquad (35e)$$

This equation is readily solved by a slide rule. The scales for such a rule are laid out as follows:

(a) The cA and the d scales are located on the fixed portion of the rule. The V, p, n and t scales are located on the slide.

(b) The cA scale is laid out with any convenient length as the unit between 0.01 and 0.1, 0.1 and 1.0, etc.

(c) The V scale is laid out with the same unit distance as the cA scale. It is located arbitrarily with the maximum value at the right end of the scale.

(d) The p scale is laid out above the V scale and located arbitrarily; it is convenient to locate the minimum value above the minimum V value. The values on the p scale are determined by the logs of the values of M as given above.

(e) The n scale is laid out according to values of the log of 1/n but labeled with the proper value of n. The unit distance between $1/n = 1$ and $1/n = 10$ is 1.0163 times the unit distance for the other scales. It is located arbitrarily; it is convenient to have the $n = 5$ mark above the minimum V value.

(f) The unit distance for the t scale is the same as for cA and V. The scale is located arbitrarily; it is convenient to have $t = 1$ above the minimum V value.

(g) The unit for the d scale is the same as for the n scale. This scale must be located in the proper relation to the other scales. This is most conveniently done by solving equation (34) for the specific set of conditions indicated by the left-hand values on the sliding scale.

Let $cA = 0.1 \times 10^{-3}$, $V = 100$, $p = \frac{1}{4}$ $(M = 0.0145 \times 10^{6})$
$n = 5$, $t = 1$

From equation (34) $d = 0.0776$ so this value would lie opposite $cA = 0.1 \times 10^{-3}$ on the fixed scale and the other values of d are thus located.

(h) A "runner" with a fine index line similar to that carried by the ordinary slide rule should be provided for proper location of specific values.

The use of the rule is quite simple. Knowing cA, V, p, n and t, to find d:

(a) Locate the runner over the proper cA value.
(b) Bring the proper V value under the runner.
(c) Slide the runner to the proper value of p.
(d) Bring the proper value of n under the runner.
(e) Opposite the value of t read the value of d.

Knowing the values of d, t, n, p and V the value cA may be determined by a similar process. It will be noted that the runner and the sliding scale are moved alternately in either case and that the operation is always one of placing the runner over the proper scale value or, with the runner in a given setting, placing the proper scale value under the runner. In other words, it is never necessary to bring the end of any scale under the runner before proceeding to the next step. It is to provide this feature of simplified operation that equation (35e) was put into the form of alternate additions and subtractions.

A rule for practical use could be made in simpler form. It is impractical to actually determine the value of n and it either must be assumed that $n = 1$ or methods adopted which will eliminate the effect of departures of n from unity. Further, if cA/V were adopted as the criterion of tightness it would be unnecessary to treat A and V separately. Then equation (35e) could be transformed into

$$\log (cA/V) - \log (1/M) + \log t = 1.0163 \log d$$

and the slide rule would bear only the p and t scales on the slide.

The slide rule may be constructed in circular form, which is somewhat more compact, is perhaps handier and probably cheaper to manufacture in reasonable quantities. On such a rule the cA (or cA/V) and d scales would be placed one above the other on the fixed portion of the rule.

Significance of "n"—When the conditions are as represented by equation (30), i.e.,

$$pv^n = p_1 v_1^n$$

then the pressure-temperature relations are

$$(p/p_1)^{(n-1)/n} = T/T_1 \tag{36}$$

Taking logs of both sides

$$(n-1)/n = \log (T/T_1)/\log (p/p_1)$$

whence $n = 1/\{1 - [\log (T/T_1)/\log (p/p_1)]\}$

Since $T = T_1 + y$ and $p = p_1 - d$

$$n = 1/\{1 - [\log (1 + y/T_1)/\log (1 - d/p_1)]\}$$

Now $\log (1 + y/T_1) = y/T_1 - (y/T_1)^2/2 + \text{----}$

and $\log (1 - d/p_1) = -d/p_1 - (d/p_1)^2/2 - \text{----}$

The squares and higher powers are negligible, so

$$n = 1/[1 + (p_1/T_1)\ (y/d)] \tag{37}$$

This is for d expressed in lbs. per sq. in. If d is expressed in ounces per sq. in., *and if T_1 is assumed to be 520°*

$$n = 1/(1 + 0.0308 p_1 y/d) \tag{37a}$$

Equation (37a) reveals the following:

(a) if $0.0308p_1y/d < -1$, n is negative. Expressed otherwise the condition must be: $d > -0.0308p_1y$

In other words y must be sufficiently large and positive and d will then be negative.

(b) if $d = 0$, $n = 0$.

(c) if $y = 0$, $n = 1$.

From equations (32) and (35) it will be noted that, V and t being constant in a given case, it is only when $n = 1$ that the value of cA varies directly as d. Therefore, in the general case the value of drop alone will not determine cA. If n departs significantly from unity it is apparent that, in practice, cA cannot be determined with reasonable accuracy unless the value of n also can be determined. Further, as shown by the equations,

$$n = d/d_o$$

i.e., n is the ratio between the actual drop and the value which would exist if there were no temperature drop.

In order to show the possible variations of n in practice, the two compartments taken above as examples will be assumed to represent approximate extremes. For these compartments Table B shows the values of n for ten-minute drops when apertures are large and small, at high and low pressures and for various boundary temperature conditions.

Although it cannot be claimed that the foregoing data are exact portrayals of conditions, it seems likely that they are reasonable approximations. If that be so the following conclusions are tenable:

(a) The value of n will vary over a wide range.

(b) The *variations* are greatest when
  (i) the volume is small
  (ii) the aperture is small
  (iii) the pressure is low

(c) Even though the temperature of the boundaries remains constant, it is unlikely that n is unity. The departure from unity increases as the volume, aperture and pressure increase.

Summary of significant equations—The pertinent equations evolved in this analysis are tabulated below and the necessary constants are appended. In all cases these equations assume that the following *standard* conditions prevail:

(a) initial air temperature $T_1 = 520°$ (60°F)
(b) air at 50% humidity, whence $R = 53.44/144$
(c) atmospheric pressure $p_o = 14.7$ lbs./sq. in.
(d) expansion of the air in the apertures is adiabatic, whence $K = 1.4$

The units which are to be employed are:

(a) weights in lbs.
(b) pressures in lbs./sq. in.
(c) pressure drops in ozs./sq. in.
(d) time in minutes
(e) volumes in cu. ft.
(f) surface area in sq. ft.

TABLE B

Time t	10 Minutes							
Dimensions	8′x8′x8′				16′x24′x60′			
Volume, V	512				23,040			
Surface, S	384				5,568			
S/V	0.75				0.2415			
Aperture, cA	0.26×10^{-3}		0.95×10^{-3}		11.52×10^{-3}		42.8×10^{-3}	
cA/V	0.5×10^{-6}		1.86×10^{-6}		0.5×10^{-6}		1.86×10^{-6}	
Pressure, p	1	10	1	10	1	10	1	10
$d_o = D(cA/V)t$	0.16	0.54	0.59	1.96	0.16	0.54	0.59	1.96

a	m	$n = d/d_o$							
+0.2	+0.02	0.39	0.93	0.97	1.15	0.91	1.20	1.21	1.31
	0	0.70	1.05	1.06	1.19	1.06	1.25	1.25	1.31
	−0.02	1.02	1.16	1.15	1.22	1.20	1.30	1.29	1.33
0	+0.02	0.87	1.12	1.02	1.21	1.18	1.29	1.28	1.33
	0	1.19	1.24	1.20	1.24	1.33	1.34	1.32	1.34
	−0.02	1.51	1.36	1.28	1.27	1.46	1.39	1.36	1.35
−0.2	+0.02	1.36	1.32	1.24	1.27	1.45	1.38	1.35	1.35
	0	1.68	1.43	1.33	1.29	1.59	1.43	1.39	1.36
	−0.02	2.00	1.55	1.42	1.33	1.74	1.48	1.43	1.37

(g) aperture area in sq. ins.

(h) temperature in °F.

The pertinent equations are:

$w = -BcA[1 - E(cA/V)t]$ lbs./min.

$y = Na + Pmt - N(F/h)(cA/S)$ °F in t mins.
where N and P depend on $L = KhtS/V$

$d = D(cA/V)t\,[1 - E(cA/V)t] - Qy$ ozs/sq. in.

$d = Dn(cA/V)t\,[1 - E(cA/V)t]$

$d = n\,[M(cA/V)t]^{0.984}$

The basic data for calculations and the pertinent constants for use in the equations are given in the following tables.

Table I—Basic Data

p_1		$\left(\frac{p_1}{14.7}\right)^{0.286}$	$\left(\frac{p_1}{14.7}\right)^{0.572}$	f(p)	F(p)	p_1		$\left(\frac{p_1}{14.7}\right)^{0.286}$	$\left(\frac{p_1}{14.7}\right)^{0.572}$	f(p)	F(p)
Gage	Abs.					Gage	Abs.				
¼	14.95	1.005	1.010	.059	.1395	7	21.7	1.118	1.250	.363	.0250
½	15.2	1.010	1.020	.099	.0977	8	22.7	1.132	1.281	.386	.0232
¾	15.45	1.014	1.028	.120	.0800	9	23.7	1.146	1.313	.409	.0218
1	15.7	1.019	1.038	.138	.0696	10	24.7	1.160	1.346	.430	.0206
1½	16.2	1.028	1.056	.170	.0564	11	25.7	1.173	1.376	.450	.0195
2	16.7	1.037	1.076	.197	.0485	12	26.7	1.186	1.407	.470	.0185
3	17.7	1.055	1.113	.239	.0394	13	27.7	1.198	1.435	.488	.0177
4	18.7	1.071	1.146	.276	.0338	14	28.7	—	—	28.7	1
5	19.7	1.087	1.182	.309	.0300	15	29.7	—	—	29.7	1
6	20.7	1.103	1.217	.336	.0272	16	30.7	—	—	30.7	1

Table II—Constants Dependent on Test Pressure

The units in which the various constants are recorded are indicated in the heading.

For example, at 2 p.s.i. gage:

$B = 15.6 \quad D = 48.3 \times 10^3 \quad E = 0.37 \times 10^3 \quad F = 33.4 \times 10^3 \quad K = 1.128$, etc.

P	B	D	E	F	K	M	Q	P	B	D	E	F	K	M	Q
Gage	1	10^3	10^3	10^3	1	10^3	1	Gage	1	10^3	10^3	10^3	1	10^3	1
¼	5.38	16.9	1.08	11.5	1.261	14.5	0.460	7	28.71	89.0	0.19	61.6	0.869		0.667
½	7.84	24.3	.75	16.8	1.241	22.8	.468	8	30.58	94.8	.18	65.6	.830	95.5	.698
¾	9.50	29.4	.62	20.4	1.219	—	.475	9	32.40	100.4	.17	69.6	.795	—	.729
1	10.93	31.9	.52	23.4	1.200	33.2	.482	10	34.03	105.5	.16	73.0	.764	—	.760
1½	13.45	41.6	.43	28.9	1.165	41.3	.498	11	35.62	110.5	.15	76.4	.734	—	.790
2	15.60	48.3	.37	33.4	1.128	48.0	.514	12	37.20	115.3	.14	79.8	.706	116.5	.822
3	18.93	58.0	.31	40.6	1.065	58.8	.544	13	38.63	119.7	.14	82.9	.681	—	.852
4	21.87	67.7	.27	46.8	1.008	68.1	.574	14	40.00	123.9	.14	85.8	.657	—	.882
5	24.46	75.8	.23	52.4	.957	—	.606	15	41.40	128.1	.14	88.8	.645	—	.914
6	26.60	82.4	.21	57.0	.911	83.2	.636	16	42.80	132.5	.14	91.8	.614	134.1	.944

TABLE III—CONSTANTS DEPENDENT ON $L = KhtS/V$

L	N	P	L	N	P	L	N	P	L	N	P
0.50	0.39	0.21	1.0	0.63	0.37	2.0	0.87	0.57	3.0	0.95	0.68
.55	.42	.23	1.1	.67	.39	2.1	.88	.58	3.5	.97	.72
.60	.45	.25	1.2	.70	.42	2.2	.89	.60	4.0	.98	.75
.65	.48	.27	1.3	.73	.44	2.3	.90	.61	4.5	.99	.78
.70	.50	.28	1.4	.75	.46	2.4	.91	.62	5.0	.99	.80
.75	.53	.30	1.5	.78	.48	2.5	.92	.63	6.0	1.00	.83
.80	.55	.31	1.6	.80	.50	2.6	.93	.64	7.0	1.00	.86
.85	.57	.33	1.7	.82	.52	2.7	.93	.66	8.0	1.00	88
.90	.59	.34	1.8	.84	.54	2.8	.94	.67	9.0	1.00	.89
95	.61	.36	1.9	.85	.55	2.9	.95	.67	10.0	1.00	.90

APPENDIX II

PROBABLE ACCURACY OF PAST DETERMINATIONS OF APERTURE AREA

It has been assumed in this discussion that compartment tightness is measured by the value of cA. Therefore, in criticizing past data, the accuracy with which this unit was determined is an important consideration.

From equation (32) of Appendix I, the drop in pressure is given as

$$d = Dn(cA/V)t\ [1 - E(cA/V)t]$$

For practical purposes the quantity $E(cA/V)t$ is negligible and the expression may be written

$$d = Dn(cA/V)t$$

whence $cA = V\left(\frac{1}{t}\right)\left(\frac{1}{D}\right)\left(\frac{1}{n}\right)d$

For purposes of this analysis, the expression for D will be taken for conditions when p is below the critical pressure. Hence, the complete equation for cA will be

$$cA = \frac{1}{2.05}\left(\frac{1}{R}\right)\left(\frac{1}{\sqrt{T_1}}\right)\left(\frac{1}{p_o}\right)\left(\sqrt{\frac{1}{\frac{p_1}{p_o}^{\frac{k-1}{k}}\left[\frac{p_1}{p_o}^{\frac{k-1}{k}} - 1\right]}}\right)(V)\left(\frac{1}{t}\right)\left(\frac{1}{n}\right)d$$

The accuracy with which cA can be determined depends on the accuracy with which each factor has been assumed or can be measured.

There are two general cases which can occur in practice: the actual value of cA may be either less or greater than the value calculated from the formula. If the actual value is less than calculated from the formula, the only disadvantage is that unnecessary corrective work may be done to search for and correct leaks of no importance. But if the true value is greater than the calculated value, the purpose of the test is defeated. The conditions of the individual factors which will create the two cases are

If	$R >$ assumed value,	$<$ assumed value
	$T_1 >$ assumed value,	$<$ assumed value
	$p_o >$ assumed value,	$<$ assumed value
	$f(p) >$ assumed value,	$<$ assumed value
	$V <$ measured value,	$>$ measured value
	$t >$ measured value,	$<$ measured value
	$n >$ assumed value,	$<$ assumed value
	$d <$ measured value,	$>$ measured value
Then	$cA <$ calculated,	$>$ calculated

Therefore, it is desirable to determine, for each factor, the likelihood of its being greater or less than the assumed or measured value.

It is convenient to consider accuracy on a percentage basis. Inasmuch as the fixed *absolute* errors can be assumed with reasonable correctness in some cases and the *percentage* errors will thus vary according to the value of the factor, it is necessary to adopt another classification of whether the conditions are favorable or unfavorable to accuracy. Consequently, each factor will be discussed as follows:

(a) under favorable conditions, i.e., those conducive to accuracy, what is the probable maximum percentage error and is it likely to be greater or less than the assumed or measured value.

(b) under unfavorable conditions, i.e., those not conducive to accuracy, what is the probable maximum percentage error and is it likely to be greater or less than the assumed or measured value.

Value of R—In the development of the equations it was assumed that the air used would be at 62°F and would have a humidity of 50%, in which case R would have the value of 53.44. The favorable conditions, of course, would be when the air was in the assumed state in which case the error would be zero. Unfavorable conditions would be caused by widely different temperature and humidity. The maximum error in R would scarcely be greater than 2% and it would appear equally likely that it would be greater or less than the assumed value.

Initial Temperature—It was assumed that, in all cases, T_1 would be 522° (62°F). Under favorable conditions, this temperature would exist and the error would be zero. The most unfavorable conditions would be a probable maximum deviation of 30° from the assumed value and the error would be 30 in 522 or 6%. It seems equally likely that in practice the error would be greater or less. Since T_1 appears as a square root, its effect on cA will be only one half the error in the assumed value.

Atmospheric Pressure—It has been assumed that p_o would be 14.7 p.s.i. (29.92 ins. of mercury). This value will actually exist under favorable conditions. Under unfavorable conditions the maximum deviation will rarely exceed 1 in. of mercury

or about 3% and it is equally likely that the deviation will be greater or less than the assumed value.

Value of f(p)—This function depends on p_1, p_o and k. There is no basis for estimating departures in the latter figure from the assumed value so it will be assumed to have no error. The probable variations in p_o have been discussed above. The value of p_1 is read ordinarily by a mercury gage. The ounce marks on such a gage are only about ⅛ inch apart and the surface of the mercury has a rather sharply curved meniscus. When such a gage is read by the unaided eye, parallax and other errors in the determination of the height of the column are certain to occur. The most precise readings, unaided by verniers or other devices, can scarcely be more accurate than ± ⅛ oz.; ordinarily they probably are no closer than ± ¼ oz. The latter figure will be assumed to be the expected maximum absolute error. The percentage error will be less for the higher pressures. The two conditions then are:

(a) favorable at high pressure of, say, 12 p.s.i. gage with atmospheric pressure of 14.7 p.s.i. absolute. Under these conditions the error in the actual value of f(p) compared to the value calculated on the assumption that p_1 was accurately determined is negligible.

(b) unfavorable at low pressure of, say, 4 oz. gage, maximum error in reading gage and 14.7 ± 0.4 p.s.i. atmospheric pressure. Under these conditions the true value of f(p) would be:

$$\sqrt{\left(\frac{15.1+\frac{3.75}{16}}{15.1}\right)^{.286}\left[\left(\frac{15.1+\frac{3.75}{16}}{15.1}\right)^{.286}-1\right]}=0.063$$

or

$$\sqrt{\left(\frac{14.3+\frac{4.25}{16}}{14.3}\right)^{.286}\left[\left(\frac{14.3+\frac{4.25}{16}}{14.3}\right)^{.286}-1\right]}=0.072$$

The assumed value, as shown in Table I of Appendix I is 0.069. Thus the error is 6 in 69 or 3 in 69, i.e., 9% or 4% depending on conditions. Since the error in reading the gage is equally likely to be over or under an average figure of ± 6% will be assumed.

Time of Observation—If time were to be determined accurately it would be necessary to employ a stop-watch. The usual practice, however, is to use an ordinary pocket watch with little effort to obtain exactness. In such cases an error of 15 seconds at the beginning and end of the test are likely. The conditions favorable to accuracy are long tests of 30 minutes duration in which case the error would be at maximum 30 seconds or 2%. For 10-minute observations and the same absolute error the percentage error would be 5%.

For all the factors discussed so far there is no way of telling what the conditions were at the time of a particular test. It is extremely unlikely that all the maximum errors occurred at any one time; the most probable average error,

according to the theory of the precision of measurements, is the square root of the sum of the squares of the individual errors. Thus, for these factors the situation is

Factor	*Max. Error*	*Square*
R	± 2	4
T_1	± 3	9
p_o	± 3	9
f(p)	± 6	36
t	± 5	25
	± 9	83

Thus, the probable average error for a large number of observations of cA due to these factors is ± 9%.

Volume of Compartment—Usually the dimensions of compartments are determined reasonably precisely and the gross volume probably is subject to negligible errors. However, it is doubtful whether permeability is given much consideration and, very likely, it is the general practice to neglect it. Thus, the actual volume of air is probably always less than calculated and the error in V is negative. The actual error would be variable. Where gross volume is large and there is little contained material in a compartment the error will, no doubt, be negligible. Where the gross volume is small and there is a considerable quantity of material within the boundaries, errors of possibly 10% may be encountered. However, for purposes of discussion it will be assumed that the maximum error under such circumstances is 5%.

Determination of Drop—For very low test pressures a water gage frequently is used and both the test pressure and the drop will be determined quite precisely. For the great majority of observations, however, mercury gages are employed. The ounce marks are only about ⅛ inch apart and the meniscus is rather sharply curved. Parallax errors are very probable. Since a drop is determined by the difference in two successive readings of the gage, the sum of the errors in each reading constitutes the error in the drop. It is not inconceivable that the error frequently is as much as ½ oz. When drops are small in value, such as ¼ oz. it is very probable that they are recorded frequently as zero. Errors greater or less than the true value seem equally probable.

Value of n—The probable value of n in practice has been discussed in Appendix I. The values calculated there for the extreme conditions encountered in practice will be assumed in this discussion.

Effect of errors due to d and n—From the foregoing analysis it is apparent that the data on past air tests may contain large errors due to d and n. The probable error which exists in any single observation covers a wide range. Even with a large number of observations no single estimate of the probable error is feasible. It is possible, however, to make estimates of the *extremes* of error which may be expected.

For purposes of analysis the extreme conditions used in Appendix I will be selected as representative. Calculations of the *possible* errors in cA will be made on the basis of those data. As an example of the calculations take the case of Compartment A with the small aperture and low test pressure:

(a) For the actual aperture of 0.26×10^{-3} sq. ins. and the test pressure of 1 p.s.i. gage the value of d/n as shown by enclosure (A) is 0.2. It is con-

cluded in Appendix I that with the assumptions made there for boundary temperature conditions n may vary from a minimum of 0.39 to a maximum of 2.00. Thus with these extremes the *actual* drop will be:

$d/n \times n = 0.2 \times 0.39 = 0.08$ ozs. min.

$d/n \times n = 0.2 \times 2.00 = 0.40$ ozs. max.

(b) If the errors in observing the drop are taken to be $\pm$ ½ oz. as previously discussed the 0.40 ozs., for instance, might have been *recorded* as 0 oz., i.e., the test pressure (gage) may actually have been 16.22 ozs. but read as 16 ozs., and at the conclusion of the test may have been $16.22 - 0.40 = 15.82$ ozs., but read as 16 ozs. Or the drop may have been recorded as 1 oz., i.e., the test pressure may actually have been 15.74 ozs., read as 16 ozs., and at the end of the test may have been $15.74 - 0.40 = 15.34$ ozs., read as 15 ozs. However, for purposes of this analysis, the conservative assumption will be made that the drop has been *recorded* to the nearest ½ oz., i.e., the actual drop of 0.08 was recorded as 0 and that of 0.40 was recorded as ½.

(c) The *calculated* value of cA/V would be determined from the *observed* drops. Thus, for a test pressure of 1 p.s.i. gage and an *observed* drop of ½ oz. the *calculated* cA/V as shown by the air test curves on page 162 would be 14×10^{-7} and, the *calculated* cA would be 0.72×10^{-3} sq. ins.

(d) On this basis the error would be

$(0.72 - 0.26)\ 10^{-3} = 0.46 \times 10^{-3}$

and expressed in per cent

$0.46/0.26 = 177\%$ *over* the actual value.

(e) By similar calculations the greatest error *under* the actual value, in this case when d is recorded as zero, will be 0.26×10^{-3} or 100%.

Representative cases which may be expected to occur in practice are summarized in the following table. It will be seen from these data that errors of very large magnitude could be expected to occur frequently. Only when high test pressures and high aperture values occur together is the error likely to be small.

Summary—The probable errors may be summarized as follows:

(a) errors due to R, T, p_o, f(p) and t in all cases may be expected to be about $\pm$ 9%.

(b) errors due to the calculation of V may be expected to be about $-$ 5% in all cases.

(c) errors due to d and n may be expected to be:

(1) least at high pressures and large apertures when errors of from 0 to about + 20% to + 50% probably will exist.

(2) greatest at low pressures and small apertures when the errors may be from $-$ 100% to about + 180%.

(3) in general the small relative apertures, i.e., small drops, may be suspected to result in quite large errors in the calculated value of cA.

To give added significance to the magnitude of the probable errors the following data on *circular* holes having areas in the range of possible errors is given:

ERRORS DUE TO d AND n

Dimensions V	8′x8′x8′ 512				16′x24′x60′ 23,040			
Actual cA Actual cA/V	0.26×10^{-3} 5×10^{-7}		0.95×10^{-3} 19×10^{-7}		11.52×10^{-3} 5×10^{-7}		42.8×10^{-3} 19×10^{-7}	
p(p.s.i. gage)	1	10	1	10	1	10	1	10
d/n	0.2	0.6	0.6	2.0	0.2	0.6	0.6	2.0
	Extreme values of n							
Minimum	0.4	0.9	1.0	1.2	0.9	1.2	1.2	1.3
Maximum	2.0	1.6	1.4	1.3	1.7	1.5	1.4	1.4
	Actual values of d							
Minimum	0.08	0.54	0.60	2.40	0.18	0.72	0.72	2.60
Maximum	0.40	0.96	0.84	2.60	0.34	0.90	0.84	2.80
	Recorded values of d							
Minimum	0	0.5	0.5	2.5	0	0.5	0.5	2.5
Maximum	0.5	1.0	1.0	2.5	0.5	1.0	1.0	3.0
	Calculated $cA\times10^{-3}$							
Minimum	0	0.23	0.72	1.20	0	10.36	32.25	54.15
Maximum	0.72	0.49	1.54	1.20	32.25	21.90	69.12	65.66
	Errors in cA in %							
Max. under actual	100	12	27	0	100	10	25	0
Max. over actual	177	88	57	22	180	90	61	53

Area, sq. ins.	*diam., ins.*
0.19×10^{-3}	1/64
0.77×10^{-3}	1/32
3.07×10^{-3}	1/16
12.27×10^{-3}	1/8
49.09×10^{-3}	1/4

In conclusion the foregoing analysis would indicate that:

(a) errors of $\pm$ 20% to $\pm$ 50% in the calculated value of cA would be reasonably frequent. Errors of $\pm$ 100% would occur at times, particularly when the test pressure was low.

(b) "plus" errors indicating apertures larger than actual would generally be of greater magnitude than the "minus" errors. This certainly promotes safety but it also demands much useless work.

(c) recorded drops of "zero" do not necessarily indicate bottle-tight compartments.

(d) the most important sources of inaccuracy in most cases are the inaccurate determination of drop and the assumption that n is unity.

STORAGE BATTERIES FOR DIESEL ENGINE CRANKING

ACKNOWLEDGMENT

The author of this article, published in the August 1952 issue of "Motorship," is E. A. HOXIE of the Application Engineering Division of The Electric Storage Battery Company.

Electrical starting of diesel engines as compared to automotive gasoline engines usually requires more careful study to determine the requirements of an adequate and economical equipment. This is due, largely, to the wide variation in the design and characteristics of diesel engines which have a considerable effect on the required torque, cranking speed and duration of cranking.

While the use of various formulas has been suggested as a means of determining the cranking requirements of a diesel engine of known power or cubic inch displacement, experience has indicated that these formulas are frequently unreliable.

Considering particularly the larger of the electrically started engines, such as the engines of engine-generator sets, marine propulsion engines and diesel-electric locomotive engines, which involve batteries of from six to thirty-two cells, the cost of the battery and the high degree of reliability required make it highly desirable to eliminate guesswork and to place the application on a sound engineering basis.

BREAKAWAY TORQUE, ROLLING TORQUE AND CRANKING SPEED

In order to select a suitable storage battery the following information should be available:

1. Maximum breakaway torque of the engine.
2. Maximum rolling torque at recommended cranking speed.
3. Recommended cranking speed of the engine.
4. Required cranking cycle.
5. Characteristics of the starting motor.
6. Minimum temperature at which the battery will be required to function.
7. A set of characteristic curves applying to the battery which will permit a determination of the current which can be obtained for the required duty cycle at the required voltage and at the required temperature.

These tabulated requirements are further discussed and elaborated upon in the following:

For the purpose of determining the requirements of the starting equipment, the term "Breakaway torque" should be construed as referring to the maximum torque required to start rotation of the engine.

However, in some cases, the maximum torque required does not occur until the first or second compression stroke is encountered.

The values of breakaway and rolling torque are considerably affected by the temperature of the engine due mostly to the higher viscosity of the lubricating oil at low temperatures.

It has been found that in some cases the torque required to start rotation immediately after a shut-down of a hot engine is higher than when the engine is cold. In these cases, the engine may be started after a short cooling-down period.

The cranking speed required to insure a start, assuming that the engine is in good condition and properly adjusted, varies, with the size of engine, number of cylinders and design. In general, the small multi-cylinder, high-speed engines require higher cranking speeds.

Unfortunately, the torque requirements of an engine, particularly a newly designed engine, are not always known. In these cases, it seems obvious that the engine manufacturer should accept the responsibility of determining the torque required and the speed of cranking to insure reliable starting. If, for any reason, actual data pertaining to the particular engine have not been obtained by test, the engine manufacturer is also best qualified to estimate the values of torque and cranking speed.

THE CRANKING CYCLE

The required cranking or duty cycle must be defined before the required capacity of the battery can be determined.

Specifications for diesel engine electrical starting equipment vary widely as regards the duty cycle which must be provided. Typical examples are:

1. Six cranking periods of 15 seconds each with 15 seconds intervening between cranking periods.
2. The equivalent of 1½ minutes of continuous cranking.
3. Ten cranking periods of 30 seconds each with 30 seconds between cranking periods.

It is appreciated that the requirements of a particular installation may indicate the advisability of providing a particular cranking cycle and that these requirements may vary.

However, the advantage of a standard cranking cycle is readily apparent from the viewpoint of both the starting motor manufacturer and the storage battery manufacturer.

Perhaps the most common cranking cycle calls for six consecutive cranking periods of 15 seconds each, closely following one another without the cranking speed falling below the required engine firing speed as determined by the engine manufacturer. This requirement is sometimes simplified so as to call for continuous cranking of the engine for 1½ minutes at a specified temperature. It is realized that in practice, the engine will seldom, if ever, be cranked continuously as long as 1½ minutes.

The actual amount of battery recuperation when discharged intermittently at high rates and, therefore, the total time of the cranking periods that may be obtained is affected not only by length of time between discharges but also by the battery temperature.

It is, therefore, suggested, in the interests of simplification, that unless

otherwise specified, storage batteries be supplied for diesel engine cranking on the basis of furnishing 1½ minutes of continuous cranking at not less than the specified cranking speed at a specified battery temperature.

The statement has often been made that a certain engine may be depended upon to start as long as the battery and starter are capable of furnishing the requirements for breakaway. In these cases, the claim is made that speed of cranking is of little or no consequence, and the engine will probably start within two or three compression strokes.

In other cases, however, particularly with the smaller high speed Diesels, it is essential that comparatively high cranking speeds be provided, and that even higher cranking speeds are required when starting at low temperatures. There are also cases where cranking must be continued for 30 seconds or longer, apparently to permit the gradual build-up of temperature in the combustion chamber until the temperature of ignition is reached.

STARTING MOTOR CHARACTERISTIC CURVES

In order to determine the battery current required and the minimum voltage at which this current must be supplied for the duration of the cranking cycle, a family of curves showing the starting motor characteristics must be available.

The information contained in these curves should include a torque versus current curve, a showing of motor r.p.m. versus current at a given voltage or voltages, a value of overall resistance of the motor, and when available, the additional resistance of the complete circuit from the battery to the starting motor.

From these curves the currents required to supply the breakaway and rolling torques and the voltages at which these currents must be provided may be determined.

BATTERY CHARACTERISTIC CURVES

To determine the size and capacity of the required battery, a set of suitable battery characteristic curves must be available.

Sufficient information should be available from these curves to permit a determination of the current available (usually in amperes per positive plate) which must be furnished by the battery for the duration of the given cranking cycle with the battery at the minimum temperature as given by the specification.

In most cases, it will be necessary for the battery manufacturer to make this determination or to produce a special curve or curves which will enable the user to read the current per positive plate directly from the curve.

Generally speaking, the familiar battery characteristic curves, in which ampere hours per positive plate are plotted against amperes at a given temperature with three voltage lines indicating initial, average and final volts per cell, are of little value in determining the performance of a battery when used in diesel starting.

In the first place, this type of curve is usually not extended far enough to include the high discharge rates encountered in engine cranking. Secondly, the voltage required to produce the cranking speed is usually limited to a value which is higher than the so-called final voltage as shown on the curve.

Another type of curve is frequently available in which the number of min-

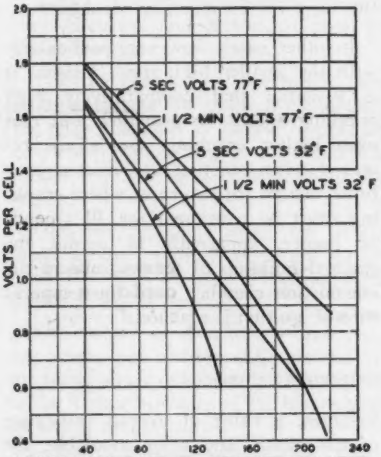


Fig. 1 Rated Voltage Characteristics Type MVAHT-Exide Ironclad Specific Gravity 1.250 at 77°F.

utes of discharge available to a final voltage of one volt/cell is indicated. This curve is also unsatisfactory for the purpose, unless the voltage required from the battery to produce the required cranking speed happens to be one volt per cell. In practically all cases, a higher voltage is required.

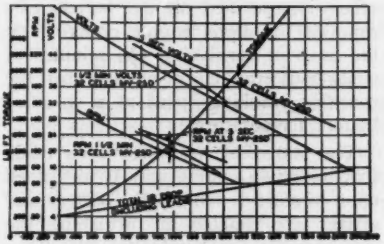


Fig. 2 Motorized Generator Operating as Starting Motor for Diesel Engine Battery Temperature 32°F.

Figure 1 illustrates a type of battery capacity curve which permits reading of the capacity per positive plate at a battery temperature of 77° and 32° F. This curve indicates the voltage at the end of a 1½ minute discharge at various currents. The 5 second lines shown on this curve are useful in determining the momentary capacity required to produce the high breakaway torques.

The important point to keep in mind when determining the size of battery required is that the voltage to maintain the required cranking speed must be available up to the end of the cranking period.

SELECTION OF THE BATTERY—A TYPICAL CASE

It may be of interest to go through the procedure involved in selecting a battery of suitable capacity to meet the requirements of a typical case.

It is assumed that the following information is available:

Breakaway torque:	2000 lb. ft.
Rolling torque:	1080 lb. ft.
Required Cranking Speed:	100 rpm.
Cranking Cycle:	Equivalent of 1½ minutes continuous cranking.
Minimum battery operating temperature:	32° F.

Motorized generator used for starting (Characteristics shown on Fig. 2)

Battery to be Used: 32 Cells Exide I/C Type MVAHT

On Fig. 2 the characteristic curves supplied by the starting motor manufacturers include the curves labeled "Volts," "Torque" and "RPM." An IR drop line showing the voltage drop internal in the motor including brush drop is also supplied. On Fig. 2, the estimated voltage drop in the wiring between the battery and the motor has been added so as to indicate the total IR drop, both internal and external, to the motor.

As mentioned later, the two curves showing 5 sec. volts and 1½ min. volts for a 32 cell MV-25D battery and the rpm at 5 sec. and at 1½ min. were

added after the size of battery required was determined.

In nearly all cases, it is found that if sufficient capacity is included in the battery to meet the rolling or cranking requirements, the larger current required for engine breakaway is automatically provided because due to the required voltage at breakaway it is much lower than the voltage required for rolling the engine.

Therefore, the usual procedure is to determine first the battery capacity required for rolling and then to make a check to determine if sufficient capacity is also available for the breakaway requirement.

From the torque curve on Fig. 2, we find that 975 amperes are required to produce the 1080 lb. ft. rolling torque.

The next step is to determine the voltage which must be produced at the battery terminals to maintain the cranking speed at not less than the required 100 rpm at the end of a 1½ minute cranking period. From the curve labeled "Volts," we find that a voltage of 38.7 impressed on the motorized generator produces a speed of 96 rpm when the motorized generator is delivering 1080 lb. ft. torque. A slightly higher voltage will be required to produce 100 rpm.

For the purpose of this example, we will consider that this motorized generator has the same characteristics as a series motor in which the speed is proportional to the counter emf. In other words, the speed is proportional to the difference between the impressed voltage and the voltage required to overcome the internal resistance of the starting motor.

The total IR drop at 975 amps. is found to be 8.3 volts. Therefore, the voltage required at the battery terminals to produce 100 rpm at 1080 lb. ft. torque must be available at the battery terminals. For a 32-cell battery.

$$38.7 - 8.3 : 96 = x - 8.3 : 100$$

in which x = the voltage at the battery terminals.

Solving for x, we find that x = 40 volts which must be available at the battery terminals. For a 32-cell battery,

$$\text{the voltage per cell} = \frac{40}{32} = 1.25 \text{ volts.}$$

In other words, a difference of 38.7 − 8.3 or 30.4 volts results in a speed of 96 rpm. It is obvious that when the difference between the battery voltage and the total IR drop is zero the speed will also be zero. Therefore, to produce a change of 1 rpm, the difference between the voltage at the battery terminals and the total IR drop must be varied $\frac{30.4}{96}$ or .3167 volt. To raise the speed from 96 to 100 RPM requires an additional voltage of 4 × .3167 volt or about 1.28 volts at the battery terminals. 38.7 + 1.28 = 39.98 which checks with the 40 volts obtained previously.

Consulting Fig. 1, we find that the type MVAHT I/C battery is capable of furnishing 85 amps. per positive plate for the required 1½ minutes at a final voltage of 1.25 volts per cell with the temperature of the cell at 32° F. Since the capacity of the battery is proportional to the number of positive plates in each cell, the number of positive plates required is $\frac{975}{85} = 11.5$ positive plates.

The battery should, therefore, contain 12 positive plates and since each cell contains one more negative plate than positive plates, the battery is designated as a 32-cell MVAHT-25 I/C.

Having determined the type and size of battery required for this typical case, the 5 second and 1½ minute voltage curves for 32 cells of type MVAHT-25 I/C may be superimposed on the motorized generator characteristic curves. The speed of cranking at the beginning and at the end of a 1½ minute period with this battery may then be deter-

mined for various values of torques and currents. These curves have been added to Fig. 3.

In this case, the MVAHT-25 I/C battery, furnishing 975 amps. is discharged at $\frac{975}{12} = 81.25$ amps., per positive plate.

By consulting Fig. 1 again, we find the actual voltage at the end of 1½ minute discharge is 1.29 volts per cell or 41.3 volts at the battery terminals. This is somewhat in excess of the 40 volts which was determined previously as the voltage required to produce 100 rpm. The actual speed may be obtained as previously explained and is found to be 104 rpm.

In a similar manner, at the beginning of the cranking period when the voltage of the battery (at 5 seconds) is 44 volts it is found that the cranking speed is 113 rpm.

The intersection of the 5 second volt line with the total IR drop line indicates the current and voltage at the battery terminals when the motorized generator is stalled. From this current, we may approximate the torque available for breakaway.

An extension of the 5 second volt line for the 32-cell MVAHT-25 I/C battery indicates that it will intersect the IR drop line at about 2250 amperes at a voltage of about 18 volts or 0.56 volts per cell.

It may be seen at a glance that the breakaway torque of 2000 lb. ft. requiring 1390 amperes is provided for with considerable to spare.

The induction of the starting motor circuit prevents an instantaneous build-up of current when the motor is energized and the motor will probably start to rotate and therefore generate a counter emf before the current reaches an $\frac{I}{R}$ value. Therefore, this stalled current of 2250 amperes will not be obtained in practice.

In every case after determining the capacity required to meet the rolling requirement for the starting cycle a check should be made to determine if the breakaway requirement can be provided.

If, under adverse operating conditions the specified rolling requirement is not completely fulfilled, the result is that the cranking time or the speed of cranking is reduced, but this does not necessarily mean that a starting failure will be encountered. However, if the full breakaway torque is not provided the starting motor is stalled. There can be no compromise in providing the full breakaway requirement.

Therefore, conservative practice indicates that a 25% factor of safety should be included when determining the capacity required to start rotation.

A word of caution is injected at this point concerning the possibility of pyramiding safety factors. The above recommendation assumes that the engine breakaway torque and starter characteristic data indicate as nearly as possible the actual requirement or performance. Naturally, if the engine torque value used includes a 25% safety factor, there is no need to include an additional safety factor when determining the required battery capacity.

BATTERY CHARACTERISTICS—MAXIMUM WATT OUTPUT

The voltage of a storage battery decreases as the load is increased, and with a fixed discharge rate, the voltage also declines as time progresses.

As a result, the watt output of the battery changes as the load is varied and also gradually diminishes with elapsed time when the load in amperes is held constant.

A study of storage battery discharge characteristics shows that for a given cell the watt output at the beginning of

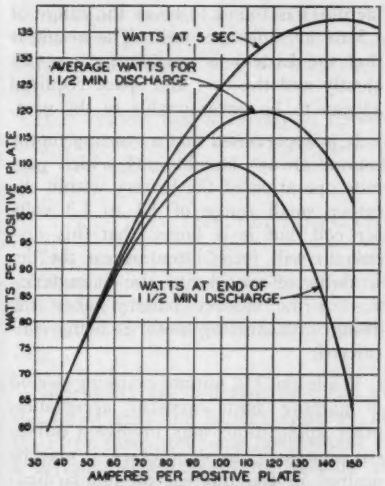

WATTS AT 5 SEC
AVERAGE WATTS FOR 1 1/2 MIN DISCHARGE
WATTS AT END OF 1 1/2 MIN DISCHARGE
WATTS PER POSITIVE PLATE
AMPERES PER POSITIVE PLATE

Fig. 3 APPROXIMATE PERFORMANCE TYPE MVAHT-EXIDE IRONCLAD TEMPERATURE 32°F

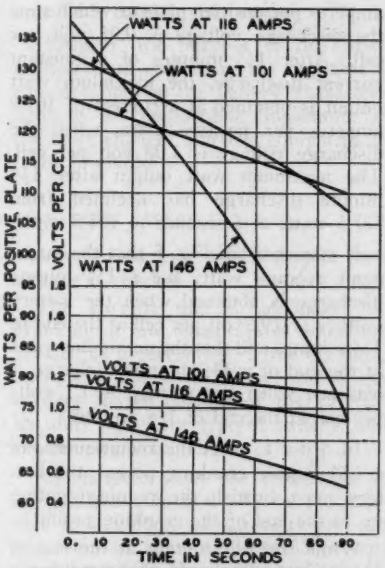


Fig. 5 APPROXIMATE PERFORMANCE TYPE MVAHT-EXIDE IRONCLAD TEMPERATE 32°F 1 1/2 MIN DISCHARGE

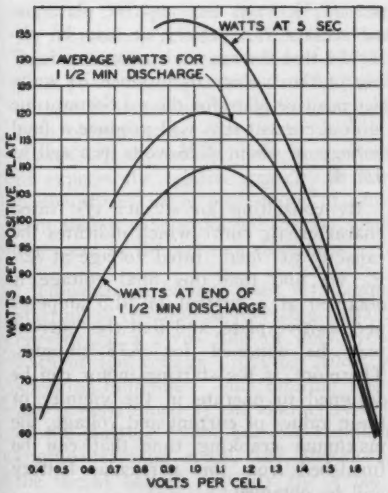

WATTS AT 5 SEC
AVERAGE WATTS FOR 1 1/2 MIN DISCHARGE
WATTS AT END OF 1 1/2 MIN DISCHARGE
WATTS PER POSITIVE PLATE
VOLTS PER CELL

Fig. 4 APPROXIMATE PERFORMANCE TYPE MVAHT-EXIDE IRONCLAD TEMPERATURE 32°F

the discharge increases as the discharge rate increases, until it reaches a maximum, and, if the discharge rate is further increased the watt output is reduced. As the duration of the discharge increases, it is also found that the maximum watt output of the battery occurs at successively lower current rates and slightly higher discharge voltages.

The attached curves, Figures 3, 4 and 5, have been prepared to show the performance of the MVAHT I/C cell at 32° F. in terms of watt output over a 1½ minute cranking period. It may be noted from Fig. 3 and 4, that, for the Exide MVAHT I/C cell, maximum watt output at 5 seconds after the beginning of the discharge period is obtained when the discharge rate is 147

amperes per positive plate at which time the discharge voltage is 0.95 volt per cell. After 1½ minutes of a constant current discharge, the maximum watt output is obtained at a current of 101.5 amperes per positive plate, when the discharge voltage is 1.08 volt per cell. The maximum watt output after 1½ minute discharge has declined from 137.5 watts at 5 seconds to 101.5 watts.

It is seen from Fig. 5 that the maximum average watts for a 1½ minute discharge is obtained when the battery voltage is 0.92 volt per cell at the end of 1½ minutes and that the maximum watts at the end of a 1½ minute discharge is obtained when the voltage is 1.1 volts per cell at the end of 1½ minutes.

In order to meet the requirements of a 1½ minute cranking period, the battery must furnish the required output up to the end of the cranking period.

While the watt output at the end of 1½ minutes is nearly the same for a 1½ minute voltage of 0.92 volt per cell, or at 1.1 volts per cell, the higher voltage is recommended from a practical viewpoint as a voltage which will permit the battery to operate at close to maximum efficiency. It should be remembered that these values refer to a battery at a temperature of 32° F.

At a higher battery temperature such as 77° F., the 1½ minute battery voltage at which maximum watts is obtained may be slightly higher than for 32° F.

A more economical installation may be obtained if the starting motor is designed to operate at a voltage of about 1.1 to 1.3 volts per cell when cranking the engine.

In applying storage batteries to the cranking of diesel engines for many years, it has been found that voltages considerably higher than this range of 1.1 to 1.3 volts per cell are frequently encountered. In many cases, the voltage required to produce the cranking speeds recommended by engine manufacturers is found to be in the range of 1.5 to 1.7 volts per cell. The result is that the battery is operating very efficiently and the cost and space required appear to be unreasonable to the user.

It is appreciated that a starting motor cannot always be obtained which permits operation of the battery within the rather small range of 1.1 to 1.3 volts per cell, but it is hoped that this discussion will focus attention on the desirability of considering the characteristics of the storage battery when the design of a starting motor is being considered.

While the 1½ minute cranking period is gaining quite general acceptance, other applications may involve a different approach. In some cases, it may be desired in the interest of standardization of battery size or because of weight or space limitations to determine what can be accomplished with a certain size and type of battery. Assuming that the required power to crank the engine is known, the required watt output from the battery can be estimated.

Considering a required battery output of 75 watts per positive plate for an MVAHT 1/C battery, it may be observed that the most advantageous loading of the battery to produce 75 watts per positive plate for the maximum time is at a current that will produce a final voltage of about 1.23 volts per cell at 32° F.

By consulting an MVAHT 1/C rated characteristic curve which indicates the capacity to "final" rated voltage at 32° F., we find that this final voltage is obtained at a current of 61.5 amperes per positive plate, and that this current may be obtained for 7.73 minutes. Therefore, if the starting motor can be designed to operate in the vicinity of these values of current and voltage, the maximum cranking time that can be furnished from this particular battery will be obtained.

It will be noted that the maximum

watt-minute output at a load of 100 watts per positive plate occurs at a lower final voltage and a higher current.

It is evident that a variety of curves may be obtained by cross-plotting, and that the subject could be elaborated upon to a considerable extent.

However, the purpose of this brief treatise is to emphasize the fact that a consideration of the battery characteristics is of considerable importance if the most efficient starting equipment is to be produced.

EFFECT OF TEMPERATURE ON BATTERY CAPACITY

This paper would not be complete without some reference to the effect of low temperature on battery capacity at current rates involved in engine starting.

Statements are occasionally made to the effect that the battery capacity at 0° F. or some other low temperature is a certain percentage of its capacity at 77° F. Information given in this manner is of little value in determining the engine cranking ability of a battery at low temperatures. A statement in which the capacity of a battery at some low temperature is referred to as some percentage of its capacity at 77° F. temperature usually means that the battery is capable of furnishing a certain current at the specified low temperature for a certain percentage of the time that this current can be produced at 77° F. This percentage of time is usually based on the final voltage being the same at both temperatures. For high rate discharges, it is usually more convenient to express the relative capacity at low temperatures as a percentage of current that can be produced for the same time and to the same final voltage.

However, a battery used for engine starting is required to furnish a certain current for a given time or duty cycle without the voltage dropping below a specified minimum. This limiting voltage is determined by the characteristics of the starting motor and the required engine cranking speed, and, therefore, the useful battery capacity for a particular installation is less than the full capacity of the battery when the discharge is continued until the rated final voltage is reached.

The current that is available for cranking at low temperatures when expressed as a percentage of the cranking current available at 77° F. varies according to the amount of the current, the duty cycle, the type of battery, and the limiting voltage.

As an illustration, the percentage of current available at 0° F. for 1½ minutes to a voltage of 1.5 volts per cell may vary as much as 38 to 53 percent depending upon the design and type of the battery.

On the other hand, if a final voltage of 1.0 volt per cell is considered for the same time and temperature, the percentage of the 77° current may vary from 41 to 63 again depending upon the design of the battery.

As a general rule, the batteries giving the higher currents at low temperatures will be less durable and will, therefore, have a shorter service life than the batteries which show a greater reduction in capacity.

A battery intended to be used specifically for engine cranking is usually designed on the basis of its ability to furnish exceptionally large currents at relatively high voltages and at the same time to give a reasonable life. This is true of batteries used in automobiles, trucks, buses, etc., and of some larger batteries using conventional pasted or "flat" plates which are commonly used for cranking stationary and marine engines.

On the other hand, the Exide "Iron-

clad" battery utilizing positive plates in which the active material is contained in slotted tubes was designed primarily to give long life in applications such as industrial truck propulsion, air-conditioning, and car-lighting on railroad cars and on Diesel electrical locomotives. It was not designed particularly to furnish exceptionally high short time currents as are required in engine starting applications. However, many users have found that the longer life and durability of this type of battery makes it particularly well adapted for cranking the larger engines and it is, therefore, used to a considerable extent for this purpose.

BEARINGS, LUBRICANTS AND LUBRICATION

ACKNOWLEDGMENT

This digest of the 1951 literature on bearings, lubricants and lubrication was published in the November 1952 issue of "Mechanical Engineering." It was prepared by Dr. J. C. Geniesse and N. A. Hartung with the assistance of the ASME Lubrication Research Committee.

JOURNAL BEARINGS AND BEARING MATERIALS

A number of advances and refinements of bearing theory were published in 1951. Burwell (1)* calculated the performance of dynamically loaded narrow sleeve bearings using the assumption of Michell, Cardullo, and Ocvirk that in narrow bearings oil flow in the axial direction is so large compared to oil flow, due to film pressure, in the direction of motion that the latter may be neglected. The resulting simplified differential equation was solved, and the results compared for several simplified types of loading with the solutions for the infinitely wide bearing with no axial flow. The general nature of the results is similar, suggesting that solutions for intermediate cases may be of similar form and determinable in terms of the two limiting solutions. Gatcombe (2) calculated the theoretical load capacity of fluid films trapped between the peripheral surfaces of rotating disks under steady-state conditions where the rim-to-rim distance is small but constant. It has not been possible to calculate performance under nonsteady-state conditions where the rim-to-rim distance varies periodically, but Gatcombe by careful experimental technique has measured the load capacity as a function of film thickness. The dynamic capacity has been observed to be as high as 6 times the corresponding static capacity, a fact which helps explain the high capacities found between gear teeth and in bearings under dynamic loading conditions.

Linn and Burwell (3) gave a complete discussion of bearings and lubrication for marine turbines and reduction gears including the fundamentals of

* Numbers in parentheses refer to the Bibliography at the end of the paper.

bearing design, construction, calculation and operation, bearing materials, oil leakage, and oiling systems. Typical calculations show that this type of bearing is designed to run at moderate eccentricities and reasonably large film thicknesses. Wilcock and Rosenblatt (4) show the key importance of oil flow in determining sleeve-bearing performance and give procedures for computing oil flow and for predicting bearing power consumption and temperature rise. Oil flow is assumed to be of two types: (*a*) The flow through the clearance space and chamfers caused by applied inlet pressure; and (*b*) the flow caused by the load-supporting pressures generated in the oil film by shaft rotation. Outlet-oil temperature is shown to be the most reasonable for determining average oil viscosity, for the bearing acts like a mixer. Outlet-oil temperature is computed as a function of average oil viscosity, and the intersection of this curve with the viscosity-temperature curve of the oil gives the operating condition for the bearing. Because of decreased shearing area in the expanding portion of the oil film, Petroff's law is found to be a good approximation up to eccentricities of 0.7. Froessel (5) discussed the advantages of subdividing bearing surfaces by cutting three or four axial grooves into the surface, thereby creating additional zones of support. Hitchcock (6) reports results on the loads, speeds, and operating temperature of roll-neck bearings. Mueller (7) discusses air-lubricated bearings and the principles determining the performance of bearings supplied with air from an external pressure source. Journal, thrust, and flat bearings are described, together with the necessity for metering orifices and the effect of clearance on the pressure distribution between the supply source and the bearing. Reduction of clearance increases the bearing pressure and effects a potent restoring force to maintain equilibrium.

Roach (8) has evaluated the ability of several typical bearing materials to tolerate abrasive dirt in the lubricant by testing in actual bearings. Rate of temperature rise offers a means of rating the embeddability performance of bearing materials. Bearings surfaced with a thin layer of babbitt will tolerate dirt with a maximum particle size about equal to the thickness of the babbitt layer. In a study of the effect of size of contaminating particles present in a lubricant upon the rate of wear encountered in an internal-combustion engine, Wellinger (9) describes bench equipment and results of tests conducted in it. Abrasive wear for a constant sliding distance is found to increase with particle size and bearing load, decrease with sliding speed, and to depend specifically on the metal pair tested.

Nowell (10) used a modified Amsler wear testing machine to study the operation of steel-backed babbitt bearings under low speed, high load conditions. Similar tests for comparing bearing materials and for comparing lubricants are proposed. Hardy, Liddiard, Higgs, and Cuthbertson (11) describe improved aluminum-tin and aluminum-tin-copper alloys. More than 1 per cent tin is found advantageous when the large tin segregations are broken up by cold-working.

Announcement (12) was made of the application of cemented tungsten carbide for journals and bearings under high speed, load, and temperature conditions where conventional bearings fail. Among other applications, high-speed, heavily loaded grinder spindles held to very close bearing clearances have been made from this material.

BALL AND ROLLER BEARINGS

Continued studies by Macks and Nemeth (13) of high-speed cylindrical roller bearings produced evidence that oil-inlet location and angle affect race temperatures. Higher single jet oil velocity reduced the temperatures whereas higher bearing speeds increased it markedly as would be expected. The effects of various operating variables on the inner and outer-race temperatures of cylindrical roller bearings at high speeds are shown by Macks, Nemeth, and Anderson (14). The significance of operating temperature is related to bearing operating limitations, and a correlation for predicting race temperatures from a single curve is given.

Aircraft gas-turbine bearing-lubrication problems are discussed by Phillips (15) with the conclusion that ball and roller bearings are superior to journal bearings and that solid oil jet feed is superior to mist lubrication. Experience shows that the entire gas turbine can be lubricated satisfactorily with a very light oil and that such an oil is necessary for temperatures below −30 F. Tests show that silver-plated or Monel separators are far superior to brass separators in preventing the formation of varnish deposits caused by high heat conditions immediately after shutdown. Detailed data obtained by Boyd and Eklund (16) on aviation gas-turbine ball and roller bearings of various sizes and designs showed the effect of load, speed, oil flow, and temperature on the behavior of the bearings at high speeds.

Krouse (17) reports formulas that have been developed for checking the actual geometric conditions which arise in ball bearings with double-curvature races in order to illustrate the effects of temperature variations across the bearing components when used at speeds encountered in gas turbines and compressors. The effect of centrifugal forces and loads in increasing the probability of failure of high-speed ball bearings is discussed by Jones (18).

THRUST BEARINGS

The development of the Kingsbury thrust bearing is described by its originator, Albert Kingsbury (19). This article, appearing seven years after Dr. Kingsbury's death, gives in condensed form a history of the inventor's career from high-school days up to the general acceptance of his bearing by the engineering world. He discusses in some detail his early activities in lubrication research, leading to the development of the pivoted-shoe thrust bearing.

A solution of the Reynolds equation for a 45-deg. "square" sector-shaped thrust bearing pad, has been given by Brand (20). The solution, obtained by means of relaxation methods, compares favorably with previously published results obtained for rectangular sliders and shows that the method can be applied safely to sector-shaped pads when the film-wedge angle is not too large.

Investigations into the friction characteristics of parallel and tapered-land thrust bearings are reported by Rorke and Blevings (21). Effects of radial taper and circumferential taper are investigated separately. The number of segments is varied by dividing an annular thrust surface by means of radial grooves. The effect of length-width ratio on the friction of the bearing is also investigated. Curves show the variation of friction coefficient with radial taper, with circumferential taper, and with length-width ratio.

Investigations of the effect of surface macroroughness on the performance of the parallel-faced thrust bearing and an explanation of its behavior are reported by M. E. Salama (22). The problem is treated both theoretically and experi-

mentally, and the main result reached indicates that macroroughness is a prime factor in the behavior of the bearing, as it provides passages which both feed the surfaces with lubricant and allow the formation of hydrodynamic films so that the performance corresponds more closely to that for film lubrication.

A new approach to the solution of the Reynolds equation for the case of plane slider bearings with side leakage has been made by Charnes and Saibel (*23*). By assuming an exponential variation of film thickness, solutions are obtained in the form of rapidly convergent series for pressure distribution, total bearing load, center of pressure, coefficient of friction and oil flow.

AUTOMOTIVE LUBRICANTS

Crankcase oil additives and their effect on oil-ring plugging, oil consumption, and engine wear are discussed by Geniesse and Schreiber (*24*). The use of the radioactive tracer technique for measuring wear is described. Fleet and engine tests under light loads reported by Howe (*25*) demonstrate that high-additive-content crankcase oils reduce engine deposits by 50 per cent and ring wear by 80 per cent.

Strang and Burwell (*26*) used radioactive chromium on plated piston rings to measure microwelding or transfer of metal to the cylinder wall. It was shown that this transfer is greatest at the top of the ring travel and somewhat less severe at the bottom of the stroke. Metal transfer was found to be independent of the pressure above the piston.

Radioactive tracer technique is described by Leicester (*27*) including several applications of which two are on lubrication. Radioactive piston rings make possible several tests between each engine dismantling; thus many tests can be run in the time previously taken by a single one when internal measurements were used to determine rate of wear. This technique also has been used with lubricating-oil additives containing radioactive sulphur to determine their role in lubrication.

METALWORKING LUBRICATION

Lauterbach and Ratzel (*28*) have demonstrated that, for low cutting speeds (below 10 sfpm), a cutting fluid gets to the cutting edge of a tool by penetrating the clearance crevice between the tool and workpiece and not by the rake crevice between the tool and chip. No information on the mechanism of fluid penetration could be determined at higher cutting speeds by any of the methods which were used.

Using the tool-chip contact as a thermocouple to measure tool-point temperature and employing techniques which give reliable results in the presence of cutting fluids, Shaw Pigott, and Richardson (*29, 30*) find that the cooling effectiveness of a fluid decreases as the depth of cut is increased or as the cutting speed is increased. Further, there is a limit for both depth and speed at which the fluid no longer reduces tool-chip temperature. They also find that tool temperatures, as determined by chip-temper colors, can be varied readily by changing cutting conditions without changing the chip-tool temperature. No correlation was obtained between cooling effectiveness and cutting friction.

Iwascheff (*31*) was able to show, in a series of tests under actual production conditions, that a flood of coolant, properly applied, improved surface finish, allowed higher cutting speeds and increased tool life. Niebusch and Strieder (*32*), in a review of several different cutting and grinding operations, also testify to the need of applying a cutting

fluid in copious quantities at the proper point and recommend, as a "rule of thumb," that flow rate in gallons of cutting fluid per minute be set numerically equal to maximum horsepower required for cutting.

The latest theories of metal cutting, with comments on the role of cutting fluid are reviewed by Merchant (33). Although not immediately concerned with research on lubrication in metal cutting, the valuable investigations of Chao and Trigger (34) on tool-chip temperatures should be mentioned since their information on the dynamics of metal cutting has application in this field.

The grinding process was investigated by Outwater (35), who examined the cutting action of single grains of abrasive. He found that the atmosphere plays a dominant role and that oxygen, even at low pressure, is remarkably effective in reducing friction in grinding. The main effect of the grinding fluid is to control the bulk metal temperature after the cutting action is completed and to reduce friction between the severed chip and uncut metal. In the fourth paper in a series on cylindrical grinding, McKee, Moore, and Boston (36) critically examine the effects of grain size and type of grinding compound in terms of volume of metal removed per volume of wheel wear, specific horsepower requirements, surface finish, surface temperature increase, hardness increase, and quench or skin effects. The merit rating of a given fluid is highly dependent upon the choice of metal and conditions of cutting and, to a marked degree upon the relative weight given to different criteria.

A special dynamometer for measuring torque and thrust loads on a drill was constructed by Brain and Hulf (37) for investigating the behavior of cutting fluids in this operation. In a review article on drilling, Sack (38) makes recommendations for increasing efficiency and includes suggestions for the selection of coolants and cutting fluids.

The surface activity of cutting fluids continues to receive special attention by a number of Russian investigators including Zhadin (39) and Epifanov (40).

Soluble cutting fluids, which constitute over half of the cutting fluids used in this country, are receiving increased research attention. Most of the work is described in connection with the process for which they are used. Lindert (41), studying them on their own merit, examined the "blue-black" spotting occasionally encountered in the use of such fluids and offers a coherent chemical explanation for its occurrence together with recommendations for its elimination. He also assesses the potential health hazards arising from bacterial contamination.

For the metal-drawing processes, sulphide and phosphate coatings received special attention during the past year. Knerr (42) describes a lead-coating process which strongly resists removal and thus permits repeated cold deformations without reapplication. Hendricks (43) discusses a low-friction sulphide coating for ferrous metals which can be formed by vapor-phase sulphurization during annealing, thermal decomposition of a predipped coating, by chemical conversion of an oxide coating or by a hot aqueous solution. A phosphate coating is recommended for the cold extrusion of steel by Hauttmann (44) while a special phosphate coating is suggested for a variety of processes (45 to 48).

Measurements of temperatures resulting from bar and wire-drawing were used by Reichel (49) for examining lubricants and coolants. Lubricants for cold-working nonferrous metals were reviewed by Chrisholm (50, 51) and for general operations by Bastian (52). Lubricants for rolling stainless steels are discussed by Bible (53).

The influence of lubricants upon the

efficiency of wire-drawing with carbide dies under a variety of conditions has been investigated by Baron and Thompson (54). Wistreich (55, 56) concludes that "ringing" or grooving of drawing dies, near the point of entry of the wire into the die, is due to the steep stress gradient in the die and is not due to abrasive solids which may contaminate the lubricant. A review of lubricants for wire-drawing is given by Snigel and Verner (57).

BOUNDARY LUBRICATION

Solid Friction. Many of the papers published during 1951 confirm the fact that solid friction is due to shearing of welds formed by plastic deformation caused by intense local loading or tangential stress (58 to 66), although Schnurmann (67) presents evidence that solid friction may be, in part, electrostatic in origin.

Studies of metal transfer or pickup on sliding, by irradiation of one surface before or after sliding, is proving to be a powerful tool for study of friction and wear (62 to 65). It is shown that metallic wear, though generally varying in the same direction as friction, may change by an enormously greater ratio, so that the coefficient of friction may not be a good index of wear.

Evidence of chemical action at the surface due to sliding is reviewed by Clayton (68). Moore and Tegart (61) have confirmed this and have advanced the view that the nature of the oxide film formed during sliding may influence greatly the nature of the wear.

Organic Boundary Lubricants. Recent work by many authors (69 to 76) has shown that boundary lubricants react with base-metal surfaces, forming a strongly oriented soap film of high melting point. When no reaction occurs, as with inactive polar lubricants or precious metals, there is evidence of strong orientation. Menter (71) reports electron-diffraction data on films of reactive and unreactive polar compounds on base and noble metals; in all cases, orientation roughly normal to the metal surface was observed. Moore (74) presents results on similar systems, using radioactive surfaces to demonstrate that reaction takes place. Hirst (73) indicates that water is necessary for the reaction between a fatty acid and metal oxide to take place.

The ability of these films to lubricate is shown by Barwell and Milne (75) to depend on the melting point of the actual lubricant—soap where reaction has occurred, or hydrocarbon where no reaction occurs. The lubricating qualities of the solid films are shown to be superior to those of melted films, that is, lubricants operating above their melting points. Shooter (76) and Moore (74) both present evidence of the need for multilayer soap films for effective boundary lubrication. The friction reduction due to a monolayer of fatty acid is small; however, in a reactive system where good boundary lubrication is observed, the formation of multiple layers of soap is observed.

Solid Lubricants. Further evidence is given by Bowden and Young (58, 59), and Finch and Spurr (60) that oxide and organic films on metals, and adsorbed gas films on diamond and gas-carbon, cause the low frictions measured on technically clean surfaces in air. Finch (77) states that the lubricity of layer-lattice lubricants like graphite and molybdenum disulphide is due to adsorbed films on the layers which lower shear resistance by facilitating a "peeling" action. These lubricants should be in the form of plates of minimum thickness and maximum surface area. Phosphate films on steel surfaces have been shown by Barwell (78, 79) and Barwell and Milne (80) to be effective aids to

lubricity, especially when supplemented with paraffin wax or molybdenum disulphide.

Fretting. The effect of molybdenum disulphide, applied by different methods, on the fretting failure of steel-glass and steel-steel combinations was determined by Godfrey and Bisson (81). Fretting cannot be prevented unless a film, thick and coherent enough to prevent all contact, is made on the surfaces. The best films delayed the onset of fretting for 28×10^6 cycles for steel-glass and 10×10^6 cycles for steel-steel.

Wear studies by Mason and White (82) on various metal-metal and metal-nonmetal combinations undergoing oscillatory tangential motion at supersonic frequencies confirm the results of previous work on metals at low frequencies in showing that there is a sharp transition between insignificant and rapid wear at a critical amplitude sufficient to cause gross slip between the surfaces. The apparatus used, described by Mason and White (82) and Mason and Wick (83), is capable of producing up to 0.005 cm. of motion from 500 to 18,000 cycles per sec. and is designed so that displacement-time curves and force-displacement curves can be followed on an oscilloscope. The volume of wear for one billion operations is found to be proportional to the product of the static force and the length of the stroke. The rate of wear falls off rapidly with time. Calculations show that only about one part in 10^9 of the energy goes into producing wear, the rest going into heat production. The critical amplitude increases as the two-thirds power of the normal load and inversely as the two-thirds power of the shear stiffness, so that materials with a low shear elastic constant such as rubber will show a lower wear rate than a stiff material such as steel. The total displacement for no slide increases as the two-thirds power of the static load. Theoretical analysis of the conditions operating in the region of no gross slip leads to the assumption that local slip occurs within the area of contact. This assumption is verified experimentally for oscillating tangential stresses applied to a spherical glass lens between two rigidly held plane glass surfaces, where theory predicts that local slip will occur between these lenses over a circular annulus (84, 85).

Thin-Film Lubrication. The question of anomalous flow of liquids between surfaces separated by very thin films is revived by Mardles (86) in experiments on the rate of spreading of pools of liquid over horizontal polished surfaces or between optical flats. This spreading behavior has been correlated with friction results on the same surfaces by Bielak, Mardles, and Tingle (87). Observed deviations from the simple mixing law are attributed to changes in the molecular association of the liquids on mixing.

Marcelin (88) reports further data on friction experiments conducted dry and with very thin lubricant films, from which he concludes that the laws of friction in a given case depend on the metals used, finish, load, lubricant, temperature, and length of run.

Tests reported by Borsoff, Accinelli, and Cattaneo (89) on spur gears with mineral oils of various viscosities developed a definite relationship between the maximum horsepower which the gears can transmit without scoring and the product of gear speed and lubricant viscosity. Introduction of a viscosity factor in the Lewis equation for gear design gives an equation consistent with data obtained by the authors. The modified Lewis equation and data show the influence of viscosity to be a factor not to be neglected in gear design.

Clark, Woods, and White (90) examined lubrication under extreme pressures with mineral-oil films, using as a bearing the contact area between crossed-

axis steel cylinders. Evidence indicating intact oil films at average pressures ranging from 86,000 to 215,000 psi is interpreted as an indication of partial oil solidification under these conditions.

Research Techniques. A method for mounting specimens for successive electron-diffraction studies while temperature is increased continuously from room temperature to 1000 C. is described by Menter and Sanders (69). The usefulness of a new technique for autoradiographic studies of metal pickup in which the surfaces are irradiated after the friction experiments are completed has been demonstrated by Rabinowicz (64). A two-ball machine was used by Lane (91) to indicate that for every combination of lubricant and sliding system there is a characteristic temperature where lubrication fails and scuffing occurs.

Miscellaneous. Studies by Critchlow and Flynn (92) of wire rope subjected to pulsating tensile stress show the importance of lubricating the core and the strands of wire rope. Static friction measurement is used by White and Zei (93) for evaluating oiliness of a large number of proprietary and specially compounded lubricants. In this work graphite and molybdenum disulphide are shown to give marked lowering in friction when added to a lubricating oil. Interesting studies of the friction of yarn treated with various lubricants against steel are described by Moss (94). There is no apparent relation between coefficient of friction and lubricant structure, paraffin wax being the best lubricant tried. A good discussion of the importance of lubrication for knitting and weaving of cottons and other textiles is given. Williams (95) reviews the properties and applications of carbon brushes and bearings.

PROPERTIES OF LUBRICANTS

Viscosity. In a symposium on methods of measuring viscosity at high rates of shear, Fenske, Klaus, and Dannenbrink (96) give determinations on a high-shear viscosimeter indicating that polymer-containing fluids become non-Newtonian at a fairly well-defined shear rate. Needs (97) shows that determinations over a wide range of temperature and rate of shear indicate that straight mineral oils show no deviation from Newtonian viscosity attributable to rate of shear, while oils containing the polymers showed a decrease in shear stress with increased rate of shear.

A progress report by Bradbury, Mark, and Kleinschmidt (98) contains a description of apparatus and methods employed in obtaining data on the viscosity of a selected group of lubricants over a wide range of pressure and temperature, together with typical charts for several lubricants. Apparatus for imposition of high shear rates on oils containing high polymers is described by Wood (99). Ward, Neale, and Bilton (100) used a high-speed rotational viscosimeter and a very thin oil film to measure the viscosity of lubricating oils, with and without viscosity-index improver, and at high rates of shear.

Synthetics. The first symposium on synthetic lubricants, sponsored by the American Chemical Society, reviews the excellent work being done in the field by these products. The work of Murphy and Zisman (101) indicates that atomic structure influences viscosity-temperature characteristics and freezing point. Their work includes studies of boundary friction, lubrication, and rust inhibition. Larsen and Bondi (102) found fluorocarbons chemically inert but with poor viscosity index while the silicones have oxidation stability and good viscosity index but are poor lubricants. Larger quantities of most extreme-pressure additives must be used than in the corre-

sponding hydrocarbons. Data comparing the properties of these fluids with hydrocarbon characteristics are given. Reysen and Gibson (103) have combined the information contained in a series of five reports concerning the relationships among physical properties of chlorotrifluoroethylene polymers in tabular and graphical form for more convenient use.

Glavis (104) presents the general effects on viscosity and viscosity index of blends of polymeric additives and synthetic ester-type lubricants. Improvement in viscosity index is obtained where the polymeric additive is soluble in the particular ester involved. Murphy, Ravner, and Smith (105) describe the oxidation-inhibition action of phenothiazinc-type compounds on a diester-type lubricating oil, in a dynamic system, over the temperature range of 100 to 175 C. in the presence of metal catalysts. Variations in antioxidant action with changes in its molecular configuration are discussed.

Millett (106) shows that polyalkyleneglycol fluids are utilized widely in lubricating and non-lubricating applications at both high and low temperature. They have good thermal stability, high viscosity index, and do not sludge. Many industrial applications are cited. Sweatt and Langer (107) describe applications of polyalkyleneglycol lubricants based upon actual performance records.

Data on organopolysiloxanes as lubricants under thin-film or boundary conditions are reported by Currie and Hommel (108). These fluids possess many desirable characteristics such as high flash points, low freezing point, extremely flat viscosity-temperature slopes, high resistance to oxidation and thermal decomposition. Greases formulated from these materials are indifferent to extreme temperature changes, have low solidification points, and remarkable heat stability. Currie and Smith (109) describe the rheological properties of the same fluids. Their data describe the behavior of siloxane fluids and lithium soap-base greases made from these fluids subjected to relatively high shear rates. Murphy, Saunders, and Smith (110) show that polymethylphenylsiloxanes have greater thermal oxidation stability than the polymethylsiloxanes. The same metals accelerate decomposition and oxidation in both. A paper by Grant and Curie (111) gives a summary of the physical properties and performance of silicone fluids and greases as used commercially and classified according to physical state, chemical structure, and kind of thickening agent used.

MISCELLANEOUS

Noncatalytic polymerization of 1-olefins produces excellent lubricating oils, according to Seger, Doherty, and Sachanen (112). Given suitable olefinic charging stocks, the conversion to finished high-grade lubricating oils can be accomplished in conventional refinery equipment.

Schweitzer and Szebehely (113) report a wide variation in the solubility constants and rates of solution of air in lubricating oils, fuel oils, and water but found the rate of evolution or solution proportional to super or undersaturation, respectively. They also discuss the phenomenon of cavitation.

Sawyer (114) reports a study comparing the catalytic effect of metals on the oxidation of mineral oils, using eight oils, nine metals, and glass. The catalytic effect of the various metals increased with increasing temperature and appeared to be dependent upon surface area.

A symposium (115) on analytical research in the petroleum industry has been published. This group of 14 papers deals with applications of spectrography, polarography, and ultraviolet and infrared spectrophotometry; recent advances in certain phases of physical and chemical testing are also treated.

BOOKS

A number of books dealing with the theory and practice of lubrication have been published recently. In a volume entitled "The Friction and Lubrication of Solids," Bowden and Tabor (116) have developed the weld theory of solid friction in great detail. Analyses of contact areas, temperatures or rubbing surfaces, frictional heating and surface damage, and the mechanisms of boundary and extreme-pressure lubrication are included. In addition, studies of bearing metals, metallic wear, and the effect of impact on lubricant films are described. This book contains a wealth of scientific data, all well correlated with the theories of friction and lubrication to which the authors subscribe and which they have done so much to develop.

Another contribution to the theory of lubrication has been made by the *British Journal of Applied Physics* (117) in publishing "Physics of Lubrication," a symposium of 18 papers containing reviews and new data on hydrodynamic, boundary, and extreme-pressure lubrication. Many aspects of boundary lubrication in particular are presented with considerable new experimental evidence. The papers containing new data have been reviewed and included in the appropriate section of this digest.

In "Lubrication: Its Principles and Practice," Michell (118) approaches lubrication problems from a theoretical point of view, which would be of particular interest to a lubrication specialist. The physical properties of lubricants, notably viscosity and flow characteristics, and bearing designs are discussed at length. The author treats boundary phenomena as a mixture of solid-contact and fluid friction, and makes no mention of polar or chemically active compounds.

Three books dealing with the practice of lubrication have appeared. Georgi (119) in "Motor Oils and Engine Lubrication," gives comprehensive coverage to the manufacture, properties, and testing of motor oils. The application of these oils and the relationship of lubrication to engine design, operation, and maintenance are treated. In "Metalworking Lubricants," Bastian (120) covers all types of fluids and compounds used in metalworking processes and in forming nonmetallic engineering materials such as plastics. Supplementing the text are illustrations of shop operations, table of fluid properties, and application charts. A fourth edition of the comprehensive treatise by Thomsen (121), "The Practice of Lubrication," deals with the properties and methods of testing lubricants and lubrication practice for the most important types of industrial machinery, including internal-combustion engines.

A compilation entitled "The Fundamental Aspects of Lubrication," has been published by the New York Academy of Sciences (122). Included are thirteen papers by authorities on various phases of lubrication. Among the subjects treated are hydrodynamic and thin-film lubrication, friction, surface damage, adsorption, grease structure, physical properties of lubricants, and metal cutting.

In the Proceedings of the Third World Petroleum Congress, Section VII (123), five papers appear dealing with viscosity-temperature-pressure relations, gear and boundary lubrication and metalworking. Six other papers in this volume treat pour depressants, greases, and motor oils.

"Physical Chemistry of Lubricating Oils," by Bondi (124) is a comprehensive volume on the physical-chemical properties of oil. P-V-T relations, rheology, surface phenomena, optical electrical properties, type analysis, phase equilibriums, and reaction kinetics of hydrocarbons in the lubricating range are discussed. A chapter on synthetic lubricants is included.

The proceedings of a conference on wear held at Massachusetts Institute of Technology in 1948, have been published by the American Society for Metals under the title "Mechanical Wear" (125). A number of the papers included in this symposium are concerned with lubrication in some degree.

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REHEAT TURBINES ARE SHOULDERING THE INCREASED ELECTRICAL LOAD

ACKNOWLEDGMENT

The author of this article, published in "General Electric Review," November 1952, is MR. ROBERT L. JACKSON, Section Engineer of the Requisition Section of the Large Steam Turbine and Generator Department, Turbine Division, in Schenectady.

The first steam turbine was built and operated more than 2000 years ago. Its application to practical use however had to wait upon developments in manufacturing methods—methods necessary to produce a machine with the close clearances and high speeds of a steam turbine.

In 1883 deLaval, Swedish engineer, built the first practical steam turbine and shortly thereafter C. A. Parsons, British inventor, designed the first multiple-stage turbine. Since then progress in design has been rapid. And a continual reduction in the amount of fuel consumed per unit of output has taken place.

A product of such design progress is the modern reheat turbine. Its development is typical of general advances made over the years.

REHEAT CYCLE INTRODUCED

A reheat cycle consists of: 1) expanding the steam part way between initial and exhaust pressures; 2) returning it to the boiler to increase the temperature; 3) completing its expansion in the turbine.

An increase of approximately five per cent in thermal efficiency is made possible in this way. Reheating increases the temperature level throughout the expansion cycle and reduces the steam's moisture content in the low-pressure stages of the turbine. It makes for definite advantages in plant economy too. A reduction of the steam's moisture content decreases erosion with corresponding decrease in maintenance. In addition, the reheat cycle allows the use of smaller boilers, condensers, and feedwater heaters. Less cooling water is needed because for a given amount turbine capacity is increased 7½ to 11 per cent.

In the twenties and early thirties improvement of existing turbine efficiencies was thwarted by available materials that limited steam temperatures to about 750 F. To offset this limitation the reheat

cycle, or resuperheating cycle as it is less commonly called, was introduced.

Despite the success of the early units, development of new metal alloys in the middle thirties turned the trend back to the nonreheat cycle. The new materials allowed increases in steam temperatures to 900 and 950 F. Accordingly, thermal performance of nonreheat turbines could equal or better the reheat turbines, and without the installation and operating difficulties inherent to their early design. As a result we built only two reheat turbines from 1931 to the beginning of the postwar period.

After the second World War, fuel—like everything else—felt the pinch of inflation, and its higher cost made it necessary to build turbines of the greatest possible efficiency. Because new materials were not available to allow large increases in initial steam temperatures, the reheat cycle was again reverted to.

Our goal in the development of reheat turbines in the postwar period was twofold . . .

Design a unit as simple and compact as a nonreheat unit.

Keep the cost increase of such a unit at a level where fuel savings would economically justify its purchase.

The program has been a success. Approximately 63 per cent of our total turbine kilowatts built or on order this year are reheat units. (In 1954 the figure will be approximately 80 per cent.)

DOUBLE-FLOW TURBINE

The first modern reheat turbine developed after World War II is the 80,000-kw tandem-compound double-flow 3600-rpm machine shown in Fig. 1. It consists of two turbine rotors—high-pressure and low-pressure—bolted together in tandem. The low-pressure section is of two parts, each taking half the steam flow.

In this design, steam at 1450 psig and 1000 F. is expanded across the high-pressure turbine, reheated at 450 psig to 1000 F. at maximum flow, and then expanded across the low-pressure turbine. (The 450 psig pressure is proportional to the flow of steam passing through the turbine while the 1000 F. reheat temperature remains constant.)

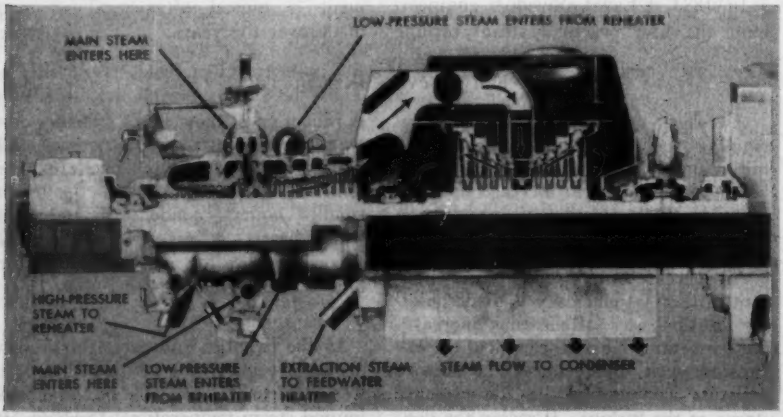

MAIN STEAM ENTERS HERE
LOW-PRESSURE STEAM ENTERS FROM REHEATER
HIGH-PRESSURE STEAM TO REHEATER
MAIN STEAM ENTERS HERE
LOW-PRESSURE STEAM ENTERS FROM REHEATER
EXTRACTION STEAM TO FEEDWATER HEATERS
STEAM FLOW TO CONDENSER

Fig. 1—First modern reheat unit built in the postwar period is a tandem-compound unit with a double-flow low pressure element and generating capacity of 80,000 kw.

Primary steam is admitted to the turbine shell at midsections and exhausts to the reheater at a point adjacent to the No. 1 bearing standard, or pedestal. From the reheater the steam enters the turbine shell at midsection once again.

With the initial and reheated steam entering at practically the same place, only the center portion of the turbine shell is subjected to high temperatures. This eliminates the severe temperature gradient that would exist were the machines designed with the flow all in one direction. It serves also to remove the highest temperature away from the bearings and water seals.

The foundation and space required for this type of unit are essentially the same as for a similar rated nonreheat unit. Having both primary and reheat admissions in the same casing results in the conservation of material and space, with better temperature distributions throughout all the metals.

Various improvements have since been made on tandem-compound double-flow turbines, and their maximum size has likewise increased. Some are now being built with ratings as high as 125,000 kw—enough electric power to supply the domestic needs of a city of 250,000.

TRIPLE-FLOW UNITS

Exhaust loss is the amount of velocity energy remaining in the steam after it leaves the last-stage buckets. It is always the goal to keep this loss at a minimum. Exhaust velocity is the ratio of steam flow to the area of the last stage: larger flows therefore require larger areas. Because larger exhaust areas in one stage are limited by mechanical stress considerations, a greater area is obtained by using more exhaust ends.

For units of 100,000- to 150,000-kw nominal rating the exhaust loss at normal back pressures would be excessive in a double-flow low-pressure section. Accordingly, a triple-flow low-pressure section with three exhaust ends is used. With such an arrangement it is necessary to separate the high-pressure section to keep the shaft spans at reasonable lengths—otherwise the critical speed at which maximum vibration occurs would approach the running speed.

The designs discussed so far are used for initial pressures up to 1800 psig, initial temperatures of 1050 F., and a reheat temperature of 1000 F. But two units now being built operate at pressure and temperatures that are the most advanced steam conditions for which a large turbine has ever been designed. These conditions are: initial steam at 2350 psig and 1100 F.; reheating to 1050 F.

Incorporating an opposed-flow high-pressure casing (initial and reheated steam flow in opposite directions from adjacent points at the midsection), the machines are similar in principle to the double-flow design.

The inner shell includes all the high-pressure stages and consists of three parts: a center portion, exposed to initial steam temperatures, machined from a solid stainless-steel forging; and two adjoining portions, one extending toward the front bearing standard and the other toward the high-pressure exhaust, made of chromium - molybdenum - vanadium castings. The external valve chest (a pressure vessel where the main steam is admitted through a series of control valves to separate nozzle arcs in the first stage) and control valves are also of stainless steel.

The maximum size of tandem-compound units coupled to one generator has increased greatly in the postwar period. Several are on order for 200,000-kw maximum capacity.

CROSS-COMPOUND UNITS

In the larger 3600-rpm tandem-compound turbines exhaust losses become quite high and it is advantageous to use cross-compound units. They consist of two separate turbines. The steam flows first through the high-pressure turbine and then crosses over to flow through the low-pressure turbine. Reheating is done as the steam goes from one to the other, or by reheating the primary steam as it expands through the high-pressure section. Cross-compound units are designed with both turbines running at 3600 rpm, or with the high-pressure unit at 3600 rpm and the low-pressure unit at 1800 rpm. When both are run at 3600 rpm, the advantages are a reduction in over-all length of the units, the use of smaller generators, and lower initial cost.

At the present time three different types of these units are being built. . . . *Unequal Load Split*—This 160,000-kw unit has a 3600-rpm high-pressure turbine carrying approximately 37 per cent of the rated load. The low-pressure section runs at 1800 rpm and carries the remainder. Both turbines comprising the unit are shown in Figs. 2 and 3. The high-pressure turbine is of essentially the same construction as the high-pressure section of a 2350-psig triple-flow unit. The low-pressure turbine is a tandem-compound double-flow unit.

Equal Load Split—The 1800-rpm high-pressure turbine for this cross-compound unit is fundamentally the same as the 80,000-kw unit mentioned earlier, except that it has doubled the capacity. It is paired with a 3600-rpm quadruple-flow turbine. Both have identical generators and share the 160,000-kw load equally.

Adjustable Load Split—A third type of cross-compound unit was first designed for a rating of 150,000 kw, with initial steam conditions of 1800 psig, 1050 F., and reheat to 1000 F. It is possible to use this design for ratings as high as 265,000 kw. (This may be done by adjusting the load-split between the high- and low-pressure units to keep the volume of steam flowing in the cross-over pipes within reasonable limits.) It was developed in an effort to minimize the length of the low-pressure section and thereby reduce space requirements. In

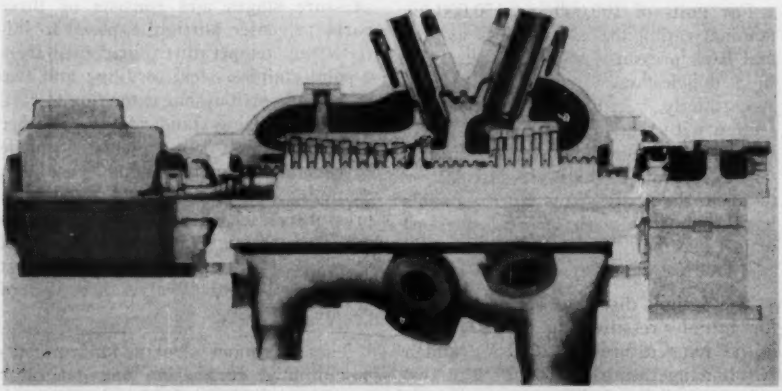


Fig. 2—High-pressure unit of a 160,000-kw cross-compound reheat turbine runs at 3600 rpm and carries approximately 37 per cent of the rated load. Steam to the low-pressure unit (below) is reheated in the high-pressure unit or as it crosses over.

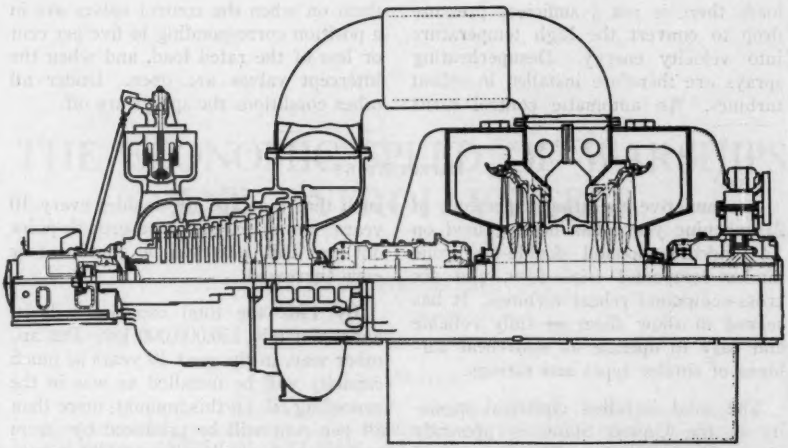


Fig. 3—Low-pressure unit of cross-compound reheat turbine runs at 1800 rpm and carries remainder of 160,000-kw load. Advantages of this arrangement are a reduction in over-all length, the use of smaller size generators, and lower initial cost.

general, such an arrangement permits a reduction of approximately 10 feet in over-all turbine-generator length of the low-pressure unit.

The high-pressure turbine of this unit runs at 3600 rpm and generates 90,000 kw. It is of the opposed-flow type and similar to the 3600-rpm high-pressure turbines of the other cross-compound units.

The double-flow low-pressure turbine is rated at 60,000 kw. It runs at 1800 rpm and has two rows of 38-inch last-stage buckets.

CONTROL

All the controls customarily used on a nonreheat turbine are required, plus some additional ones.

The steam in the reheat section of the boiler and its connecting piping contains considerable energy. With sudden loss of load, such as the opening of a circuit breaker, this energy will cause the turbine to overspeed. To prevent the speed from exceeding that required to trip the emergency governor, an intercept valve is used to shut off the unwanted steam.

Originally only one intercept valve was used, but the standard practice now is to use two. This modification permits either valve to be closed completely for testing any load, without causing more than a six to eight per cent load drop. The valves are under control of a pre-emergency governor; they start to close at 101 percent of normal speed and fully close at 105 per cent.

During starting, and also when operating at no-load speed following sudden loss of load, the temperature of the steam from the reheater will cause excessively high temperatures in the exhaust hood. The reason is that the steam from the reheater is at a high temperature; at no load or extremely light

loads there is not a sufficient pressure drop to convert the high temperature into velocity energy. Desuperheating sprays are therefore installed in reheat turbines. An automatic control turns them on when the control valves are in a position corresponding to five per cent or less of the rated load, and when the intercept valves are open. Under all other conditions the sprays are off.

EXPECTATIONS

A cumulative operating experience of 21 machine years has been gained on 12 tandem-compound double-flow, one tandem-compound triple-flow, and six cross-compound reheat turbines. It has served to show them as fully reliable and easy to operate as nonreheat turbines of similar types and ratings.

The total installed electrical capacity in the United States is presently about 75,000,000 kw, 72 per cent of which is represented by steam turbines. Its growth to this figure follows a curve such that the capacity doubles every 10 years. Estimates of future growth point out that this rate will be continued or even increased.

By 1962 the total capacity will be approximately 150,000,000 kw. Put another way, in the next 10 years as much capacity will be installed as was in the preceding 50. Of this amount, more than 80 per cent will be produced by steam turbines. According to present trends practically all of them will be reheat turbines of the larger sizes.

THE ECONOMIC SPEED OF WARSHIPS AND PATROL VESSELS

K. M. HEGGSTAD

THE AUTHOR

MR. KAARE M. HEGGSTAD, M.N.I.F., member of the Society, has studied Mechanical Engineering and Naval Architecture at technical institutes in Norway and Sweden (HTS-1931, GTI-1933), and at the Norwegian Technical University (NTH-1935). He has served both in the Royal Norwegian Navy and in the Norwegian Merchant fleet, and has been employed at different works and shipyards in Norway, mainly in connection with diesel-engine design and research. In 1947 he was appointed Chief Engineer (civilian) in the Norwegian Navy's Bureau of Ships, where he is mainly in charge of submarines, new design, modernizing, research and trials. With the aid of fellowships from the Norwegian Navy and the Norwegian Council for Scientific and Industrial Research, he has studied gas-turbines and diesel-engines in Sweden, Switzerland, Great Britain and U.S.A. He is author of numerous papers in Scandinavian technical periodicals, dealing mostly with heat engines, ships and submarines.

To estimate the "Economic Speed" (ES) for a certain ship is not a simple problem. This speed does not necessarily coincide with the one at which the specific fuel rate per S.H.P. is the least, this would usually occur at ¾ of full power or at a speed of about 90 per cent of full speed. Nor does the lowest fuel consumption per nautical mile express any meaning, as this consumption will always decrease with the speed.

Some engineers consider that the ES occurs when "Oil consumption for main and auxiliary engines divided by Speed" is a minimum, i.e., the speed at the point where a tangent through the origin touches the speed-oil consumption curve. Others prefer to state that the ES is just before the "humps" in the speed-power curve, which always occur (more or less pronounced) for values of $v/\sqrt{L} = 0.8$, 1.0 and 1.5 (v = speed in knots, L = length of ship in feet.)

There seems to be a distinction between different points of views, that of the Naval Architect, the Marine Engineer and the Shipowner. When the Government is the shipowner, the *Naval* Engineer will have to consider all three points.

Basically, the word *Economy* must be connected with the terms *Cost* or *Expense*, and on this presumption the following may be regarded as an attempt to calculate in an easy manner the economical speed of patrol vessels. The method can hardly be adapted to other than Naval and Coast Guard vessels, because merchant ships are influenced by commercial circumstances which can not be generally calculated.

The definition of the term Economic Speed will then be: "The speed at which the total expenses per nautical mile are at a minimum."

The running expenses for a commissioned naval ship may be divided into: 1) *Permanent expenses,* which are the same whether the ship is underway or not, and 2) *Speed expenses,* which are only connected with the proceeding of the ship under her own power.

Permanent expenses include first of all the cost of the ship (less scrapping value) per time unit of the estimated time of service (lifetime). Further it includes the cost of maintenance and spare parts used for ship and machinery (except propulsion and navigating machinery), and payment and cost of provisions for officers and crew. Also the cost of generating heat and light must be included.

Speed expenses cover the cost of fuel and lubricating oil consumption and the cost of spare parts for all engines in motion only when the ship is under way, and the maintenance of this equipment as far as this is done by yard workmen.

The sum of these two kinds of expenses, expressed per nautical mile covered per hour, will show a minimum for a certain speed, which in consequence is the most economical.

Permanent expenses per nautical mile.

These are $P_1 = k_1 / v$ (dollar/nautical mile)

where k_1 = permanent expenses, in dollar/hour,

v = speed in knots (nautical miles/hour).

(It must be remembered, that only during that part of the ship's lifetime when she is under way does the term "Economic Speed" bear any meaning. During the rest of the time the permanent expenses per nautical mile are infinite.)

Speed expenses per nautical mile.

In the first instance we make the assumption (see later) that the fuel consumption per SHP-hour is constant ($= b$) at any load. If the vessel needs N_x SHP to make v_x knots, the cost of fuel per nautical mile will be $p_f = \frac{N_x \cdot b \cdot P}{v_x}$

where $P =$ cost of fuel in dollars, per unit of "b".

Now the power N varies with the cube of the speed v, ($N = k \cdot v^3$), —hence we can write:

$p_f = k \cdot b \cdot P \cdot v^2$, or generally: $p_f = k_f \cdot v^2$.

The cost of lubricating oil and, without too great approximation, the cost of the wear of the engines, may each be assumed to vary with the square of the speed. In another way, we may say that the *burning* of a certain quantity of fuel will cost an additional per cent "c" of the fuel cost, regardless of the *time* used to burn it. Speed expenses per hour will then be $k_2 = k_f \cdot c = N_x \cdot b \cdot P \cdot c / v_x^3$, and Speed expenses per nautical mile $= P_2 = k_2 \cdot v^2$ (dollar/nautical mile).

The author has found the factor "c" to be between 1.2 and 1.4 for diesel powered ships; for other types of engines the factor may be a different one.

The total cost per nautical mile will now be:

$$P_t = P_1 + P_2 = k_1 / v + k_2 \cdot v^2 \text{ (dollar/nautical mile)}$$

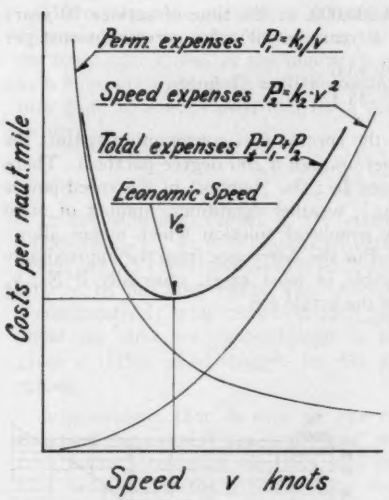

Perm. expenses $P_1 = k_1/v$
Speed expenses $P_2 = k_2 \cdot v^2$
Total expenses $P_t = P_1 + P_2$
Economic Speed
V_e
Costs per naut.mile
Speed v knots

FIGURE 1.

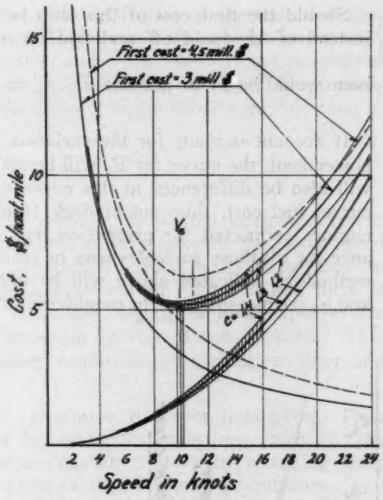


FIGURE 2.

Figure 1 shows the variation of P_1 and P_2 with the speed of the ship, P_1 being a hyperbola and P_2 a parabola. The sum of these two curves shows a minimum. By single derivation of the formula we get

$$\textit{The economic speed } v_e = \sqrt[3]{\frac{k_1}{2 \cdot k_2}} \text{ (knots)}.$$

A very simplified example will illustrate the influence of the factor "c":

With a cost of ship of $3,000,000 and a lifetime of 15 years	$200,000 annually
Maintenance and provisions	100,000 annually
Permanent expenses annually	$300,000

$$k_1 = \frac{300000}{365 \cdot 24} = 34.3 \text{ dollars per hour.}$$

Main engines: diesels; 2000 SHP at 11 knots; fuel oil consumption, "b" = 0.44 lbs/SHP/hr; fuel cost, P = $0.02 per lb; assumed factor c = 1.3. Then

$$k_2 = \frac{2000 \cdot 0.44 \cdot 0.02 \cdot 1.3}{11^3} = 0.01722$$

The economic speed will then be

$$v_e = \sqrt[3]{\frac{34.3}{2 \cdot 0.01722}} = 10 \text{ knots.}$$

With c = 1.2 or 1.4 the ES will be 10.25 or 9.75 knots respectively, a variation of only 2 5 per cent either way.

This example is illustrated in Figure 2. From this it will also be seen, that in this case it is just as expensive to proceed at 6 knots as at 15 knots.

Should the first cost of this ship be \$4,500,000, or the time of service 10 years instead of 15 (paid off and laid up for 5 years in all), the permanent cost per hour would be \$45.6, and the ES, $v_e = \sqrt[3]{\frac{45.6}{34.3}} \cdot 10 = 11$ knots.

If account is made for the variation of the specific fuel consumption against the power load, the curve for P_2 will be another and not a 2nd degree parabola. There will also be differences in this curve caused by: the "humps" in the speed-power curve, fuel cost, time out of dock (fouling), weather conditions, number of main engines connected for propulsion, etc. A graphical solution which makes allowance for all these variables may be made. But the difference from the approximate method as indicated above will be negligible in most cases, especially if N_x, v_x and b_x are measured in the neighborhood of the actual ES.

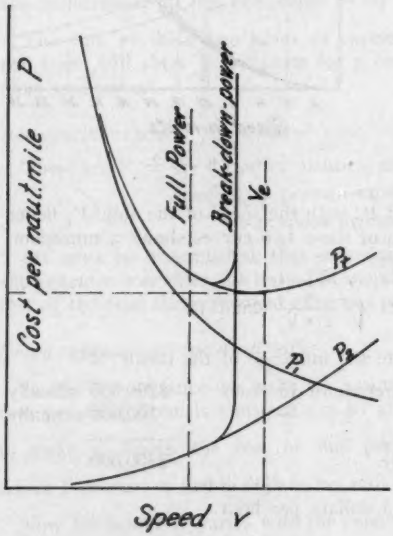


FIGURE 3.

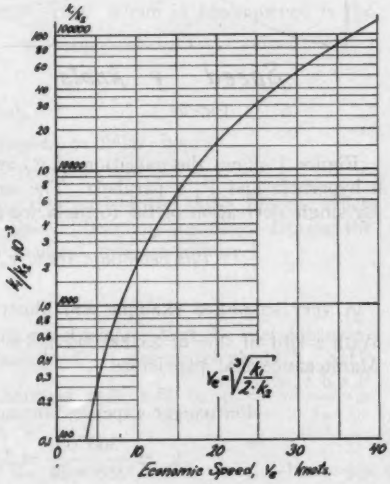


FIGURE 4.

Now it may happen that for a certain ship this calculated ES will be in excess of the performance of the existing propelling machinery. When the speed is raised more than, say 25 per cent above the speed at full power, the engine will have a 100 per cent overload, resulting in breakdown and consequently in a sudden vertical rise in the P_2-curve. This case is illustrated in Figure 3. Here the propulsion machinery is too small for an economical use of the vessel if the assumed time of service is to be of the corresponding shortness, or if the permanent expenses are to be kept at that high level. In this case the full power should then be regarded as corresponding to the most economic speed. Hence, in a warship, the cruising speed should be around the economic speed, and the cruising power chosen should be about ¾ of full power of the cruising machinery.

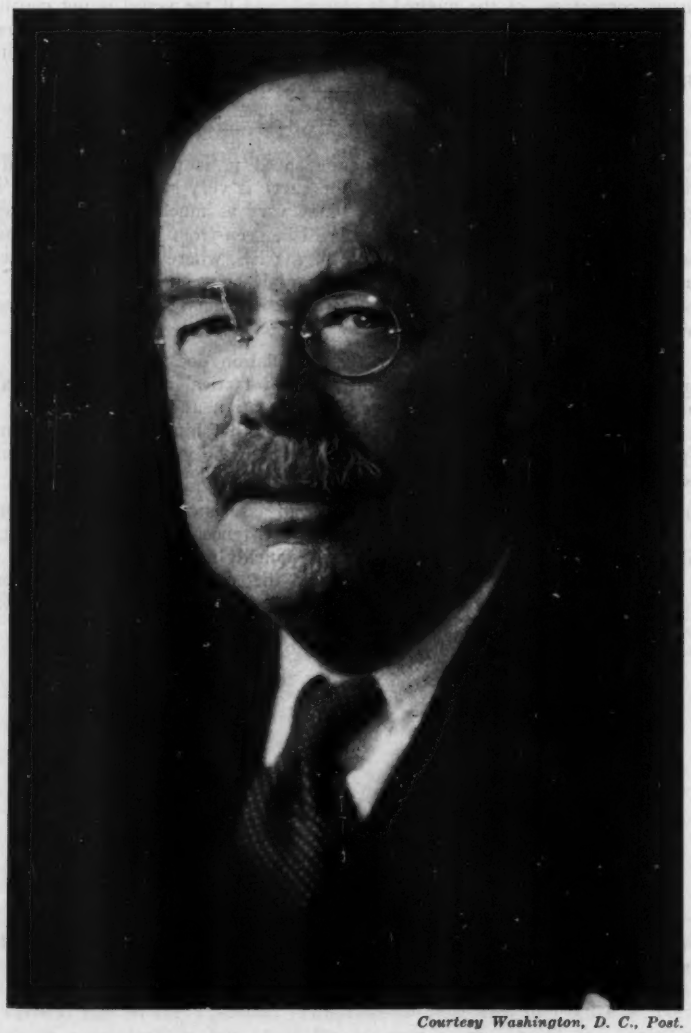
The results here outlined will remain the same regardless of the time the commissioned ship is under way during the year. If the vessel was always under way, the basic correctness of the method is obvious, and if the vessel is not considered as a ship when not underway the method is just as correct. It is possible to show in a quite analogous way, that for a certain distance S, the most economic time to be used is

$$t = S \cdot \sqrt[3]{\frac{2 \cdot k_2}{k_1}} \text{ or } te = S/v_e$$

In the diagram, Figure 4, the economic speed v_e is plotted against different values of k_1/k_2. It will be noticed that the curve is very steep at the lower speed range, at 10 knots the coefficient k_1/k_2 may vary as much as $\pm$ 30 per cent to alter v_e by one knot either way. Also it will be seen from Figure 2, that there is a comparatively wide range on each side of the ES, where the total expenses are about the same per nautical mile, in the example between 8 and 12 knots. This gives a rather good margin for the altering conditions of fouling, weather and prices.

It is evident, that in time of war this calculation does not hold good. Then the most "economic" speed depends on a lot of tactical questions, such as "the time factor," refueling facilities, the general situation and so on, changing from case to case. As the probable time of service of the ship may be cut down, and the price of ship and crew as a fighting unit may be invaluable, the "economic speed" will be very high anyway.

On the other hand, in time of peace, as an assurance against aggression, the real value of a war vessel lies in its mere existence, the knowledge that it is capable of a certain speed and that it will be quickly manned by an efficient crew. For to gain this, the men need training and the ships need shakedown periods. During these, it would be of advantage to the navy budget to keep the ES for cruising.



Courtesy Washington, D. C., Post.

MONTGOMERY MEIGS TAYLOR, U. S. NAVY
PRESIDENT, 1926

OBITUARY

MONTGOMERY MEIGS TAYLOR

On 21 October, 1952, the Society lost, by death, its 29th President, Admiral Montgomery Meigs Taylor, U. S. Navy, Retired.

While serving in the office of the Chief of Naval Operations, Admiral Taylor was elected President of the Society and served in 1926.

Admiral Taylor's naval career began with his appointment to the Naval Academy in 1886 and ended at the age of 64 while he was in command of the Asiatic Fleet in 1933. He served in the *Olympic* with Dewey at Manila Bay and in several billets, including command of the *Florida* with the Grand Fleet during World War One. His last two years of active duty were in the area and at the time, 1931-3, when the Pacific portion of World War Two was being finally generated. At this time he became noted for his diplomacy and tact in dealing with the Japanese.

Admiral Taylor survived his retirement by 19 years. He died at the age of 83 at the Bethesda Medical Center.

Courtesy Farragut Academy.

SAMUEL SHELBURN ROBISON, U. S. NAVY
PRESIDENT, 1915

SAMUEL SHELBURN ROBISON

On 20 November, 1952, death took the Society's 20th President at the age of 85, Admiral Samuel Shelburn Robison.

Admiral Robison was one of the Society's oldest members, having joined it on September 12, 1910, more than 42 years ago.

Admiral Robison had a distinguished naval career from his graduation from the Naval Academy in 1888, the year the Society was founded, until his retirement with the rank of Admiral in 1932. While serving on duty in Washington, he was elected President of the Society and served it well in that office during 1915.

DISCUSSION

AUTHOR'S REPLY

to

COMMANDER WALTER J. BUCKLEY, USN AND
LIEUTENANT DANIEL MAHONEY, USNR

Editor's Note: *Received too late for inclusion in the November 1952 issue of the* JOURNAL.

Since Lieutenant Mahoney substantially agrees with the data given in my article, "Wartime Logistics Aboard Ship," appreciation is expressed for his comments.

It is not believed that the first four paragraphs of CDR Buckley's discussion constitute objective discussion requiring comment.

With respect to his numbered paragraphs, the following is submitted:

1. This refers to paragraph e on page 283 where it was stated "to maintain designed conditions as nearly as possible." In addition to using the conventional fuel oil transfer system to transfer oil, and to ballast empty tanks, care was taken originally to stow all expendable stores so their consumption would assist in keeping best trim. It will be of interest to CDR Buckley to note the article on page 9, August 1952 issue of Bureau of Ships Journal, by Mr. Charles S. Moore, "Ships Watch Weight to Stay Fit."

2. The waste oil consisted of crankcase drainings from motor launches, emergency and casualty power diesel sets, aircraft engines (oil was changed by V Div. after 25 hours use) and one of the three vessels averaged was a CVE, spent turbine lube oil (on the *Indianapolis* the main lube oil sump tanks were of riveted construction, located in fuel oil double bottom tanks, and there was constant leakage of fuel oil into two of the main lube systems, requiring complete change of oil every 2 to 3 months). In addition, the principal auxiliaries on the *Indianapolis* were geared turbine drive. On all three ships the hydraulic oil in all deck and gunnery hydraulic systems was drained once a year.

3. Naturally the toxic nature of the material in the fluorescent lamps was taken into consideration. Due to proper care, none of these bulbs were ever broken, either by shock or carelessness. Their careful and well-planned use not only helped reduce the fuel bill but materially promoted comfort where used.

4. This question overlooks the fact that it makes little difference whether the steam pressure in the heater is 100 psig or 10 psig, when the oil pressure varies from 125 psig to 250 psig, as was customary practice on the ships referred to. Is the Commander thinking of lube oil coolers?

5. On the three ships concerned, laundry wash water was heated directly

with live steam by direct contact, not through heat exchangers.

6. An Orsat. Incidentally, CDR Buckley would be interested in reference 2, which gives data as to similar good results obtained by the use of 25% excess air in eliminating slag formation in central station boilers burning pulverized coal.

One of the intents of "Wartime Logistics Aboard Ship" was to cause all readers to appreciate the vital importance of fuel oil to the Navy. The country is using up petroleum and its products at the rate of 7,000,000 bbls. per day. Petroleum is a valuable raw material for many important chemicals. It is believed all naval officers and design engineers should read "Coal-Fuel of the Future" by Eugene Ayres, Technical Assistant to the Executive Vice President, Gulf Research and Development Company, in the April 1952 issue of Coal Age.

DISCUSSION

BY G. M. DUSINBERRE

Unsteady State Heat Conduction

BY GEORGE LEPPERT

(Jour. A.S.N.E., Vol. 64, No. 3, August 1952, p. 611)

(Professor of Mechanical Engineering, Pennsylvania State College, State College, Pa., Member A.S.N.E.)

The writer is always glad to see extensions of the use and application of numerical analysis, and the subject paper is a valuable contribution in this field. The second example, involving heat generation, is one where the Crank-Nicholson method shows up to good advantage.

It may be pointed out that the possibility of handling temperature-dependent properties is shared equally with the earlier numerical methods.

The comparison of methods in the case of the homogeneous slab is incomplete because the author does not show the short-cut obtainable by using a coarser network when the time is relatively long. For example, at 5 hours the temperature distribution is adequately established by three points. Then if $\Delta x = \frac{1}{2}$ and $M = 3$, $\Delta t = 5/12$ hr. The calculation can be done by mental arithmetic, and runs as follows:

$t/\Delta t$	θ_{10}	θ_5	θ_0
0	500	0	0
1	1000	167	0
2	1000	389	111
3	1000	500	296
4	1000	599	432
5	1000	677	543
6	1000	740	632
7	1000	791	704
8	1000	832	762
9	1000	865	809
10	1000	891	846
11	1000	912	876
12	1000	929	900

This is certainly shorter than the Crank-Nicholson procedure.

For a rough estimate, use $M = 2$, and, to two significant figures, the calculation runs:

0	50	0	0
1	100	25	0
2	100	50	25
3	100	62	50
4	100	75	62
5	100	81	75
6	100	88	81
7	100	90	88
8	100	94	90

This crude calculation gives as much accuracy as the data would justify in many practical cases.

BOOK REVIEW

THE STRUGGLE FOR AN ENGINE OR THE FIRST DIESEL ENGINES IN AMERICA

By Eugen Diesel and Georg Strossner

Publisher: Erich Schmidt Verlag, Berlin

Reviewed by E. C. Magdeburger

The book deals with the efforts made by the St. Louis brewer, Adolphus Busch, at the turn of the century to make America conscious of the need for the most efficient way to produce power out of its fast developing resources of crude oil. It is based on the research made by the son of the inventor to trace, if possible, the birth of an idea in the mind of a struggling young mechanic and engineer who demonstrated to the world that a rational approach to the problem is bound to result in an ingenious solution of it, if persisted in long enough.

Every development has a very humble beginning, a seed. If James Watt was moved by the whistling kettle of his English fireside so the "Compression Lighter" of the vocational school in Augsburg, Bavaria must have kindled the fire in Rudolph Diesel's soul that would not let him rest until compression ignition became the distinguishing feature of his proposal for a new type of engine.

American history is replete with the names of men who came modestly to its shores, made good and burned with the desire to return its favors in some substantial, unmistakable way. Adolphus Busch made good by creating the means to supply America with its best beer and was willing to pay one million marks for the right to supply America with this outstanding new engine. But that was not enough, many problems had to be overcome. The grand old man died in 1913 followed by Diesel himself (1913) and by Colonel E. D. Meier (1914), his principal associate and technical god-father of the diesel engine in America. But he died feeling sure that the engine had finally taken root on this side of the ocean.

The authors, with the aid of authentic documents from the archives of the MAN company where Mr. Strossner is the publicity director and where the engine was originally developed, deal with the study of this tragic epoch when the engine bravely held its torch high in America trying to attract the engineering talent that would eventually lead it to Detroit and its final triumph in mass production.

The book is in German, but efforts are being made to have it available in English translation also. It is highly recommended to engineers who must sell their ideas daily—to encourage them; to business men who keep on choosing the winner —to teach them patience; and to all lovers of history as it is being made in our lifetime.

MARINE FOULING AND ITS PREVENTION

PREPARED FOR BUREAU OF SHIPS, NAVY DEPARTMENT, BY WOODS HOLE OCEANOGRAPHIC INSTITUTION, WOODS HOLE, MASSACHUSETTS

× + 388 PP.; ILLUSTRATED, 1952, UNITED STATES NAVAL INSTITUTE, ANNAPOLIS, MARYLAND; $10.00.

This book reports on the results and findings of ten years of research on the marine fouling process and preventive techniques. During those ten years tests of materials and paints were made in all the waters of the world. This volume contains the reports of, and the findings from, those tests.

Some typical findings are:

Within six months out of dock a 10,000-ton warship could lose, as result of fouling, from 1½ to 2 knots of its rated speed for a given horsepower; and power to drive the ship back up to her rated speed would require a 50 per cent greater fuel consumption. An ex-Japanese destroyer in tests showed a loss of 4.6 knots out of a given 20-knot speed after one year out of dock. In another case a U.S. destroyer, after only 8 months out of dock, required double horsepower to maintain a given speed of 14 knots.

Mussels were found upon occasion to accumulate at a rate of one pound per square foot of surface per month, and barnacles at half that rate. One navigation buoy in the Woods Hole region during a three-year period accumulated 25 pounds of marine fouling per square foot.

An idea of the contents of "Marine Fouling and Its Prevention" may be obtained from the following list of Part and Chapter headings:

(I) PROBLEMS OF FOULING—The Effects of Fouling; Ship Resistance.

(II) BIOLOGY OF FOULING—The Fouling Community; Temporal Sequences and Biotic Successions; The Seasonal Sequence; Quantitative Aspects of Fouling; Geographical Distribution; Relations to Local Environments; The Principal Fouling Organisms; Species Recorded from Fouling.

(III) PREVENTION OF FOULING—The History of the Prevention of Fouling; The Invention of Protective Devices; Factors Influencing the Attachment and Adherence of Fouling Organisms; The Prevention of Fouling with Toxics; The Physical Chemistry of Compounds of Copper and Mercury and Their Interaction with Sea Water; Mechanisms of Release of Toxics from Paints; The Dissolution of the Matrix and Its Ingredients; Characteristics of Anti-fouling Coatings; The Design of Anti-fouling Paints; The Testing of Anti-fouling Paints; The Fouling of Metallic Surfaces; Interaction of Anti-fouling Paints and Steel.

This book will be of interest and importance not only to the naval service, but also to commercial shipowners and operators, shipyard managements, yacht owners and manufacturers of marine construction materials and paints.

ESSENTIALS OF MICROWAVES

By Robert B. Muchmore

236 pp., Illus., 1952, John Wiley and Sons, Inc., 440 Fourth Avenue, New York 16, N. Y., $4.50.

Reviewed by H. R. Graybill

It is probably fair to state that the impact of frequency-modulated (F-M) radio broadcasting and television has brought to most persons an awareness that there is a part of the electromagnetic wave spectrum between the familiar radio broadcast band and the infra-red region which is available for many new communication channels and new fields of research. Very-high frequency (VHF) and ultra-high frequency (UHF) are terms which are rapidly becoming part of our everyday language, and it seems not unlikely that super-high frequency (SHF) and extremely-high frequency (EHF) will soon also be as familiar.

However, at the present time most persons are perhaps unaware of the differences in techniques and equipment which are required for the generation, transmission, and reception of higher frequencies, or of the many new developments taking place in this field.

The author of this book defines the study of microwaves as the study of that portion of the radio frequency band which includes frequencies of from about three hundred megacycles per second to around one hundred thousand megacycles per second. Thus, the ultra-high frequency band, the super-high frequency band, and about one-fourth of the extremely-high frequency band fall within his discussion.

"Essentials of Microwaves" provides the reader with a non-technical approach to the study of microwave apparatus and its function. This book enables the radio engineer, the electrical engineer, the physicist and the chemist to gain a general understanding of the subject by a reexamination of principles with which he is already familiar, without attempting to follow mathematical analyses. The author begins with a review of the basic laws governing electromagnetic fields and shows how they can be interpreted to explain microwave phenomena. Later chapters describe various types of coaxial transmission lines and wave guides and special antennas, electron tubes, and other equipment suitable for microwave applications. Additional chapters describe the operation of radar systems, microwave radio systems, and apparatus of interest to the physicist and chemist, including linear type particle accelerators and microwave spectrometers. Of unique interest is a description of an "atomic" clock, which has a maximum deviation from accuracy of about three seconds in a year.

NARRATIVE OF THE EXPEDITION OF AN AMERICAN SQUADRON TO THE CHINA SEAS AND JAPAN

By

COMMODORE MATTHEW C. PERRY, U. S. NAVY

Edited with an Introduction by

SIDNEY WALLACH

Foreword by

REAR ADMIRAL JOHN B. HEFFERNAN, U.S.N.

Published by COWARD-McCANN, INC., NEW YORK

305 pages Price $5.00

In 1953 the centenary of Commodore Perry's epochal cruise to Japan with its consequent addition of the Japanese Empire to the family of nations, will be commemorated. It seems particularly apt that this volume should be published at this time. Mr. Wallach has condensed the original three volumes of Commodore Perry's narrative report and with some editing, has produced a publication which carries the authenticity of the original work with the elimination of much of lesser essentiality. The result is a very readable and highly interesting account of one of the high spots in Naval, nay in National history.

WIND, STORM and RAIN

By

DENNING MILLER

with a preface by

E. J. CHRISTIE, METEOROLOGIST IN CHARGE, U. S. WEATHER BUREAU, N. Y.

Published by G. P. PUTNAM'S SONS, 210 MADISON AVE., NEW YORK CITY

Price $3.95

Reviewed by LIEUTENANT (JG) J. A. CARMACK, JR., U.S.N.

Written for the "sportsman or father with a family picnic in prospect," toward "the greater enjoyment of his leisure time," this book allows just that when the library or easy chair is the place of leisure. Written in an easy, clear style, it provides interesting reading, but fails in its purpose of enabling the average man to better predict future weather. As a book it might better be titled: "The Earth, Its Formation, Composition, and Atmosphere," for this is Mr. Miller's subject.

This reader, the average man, knows that increasing cloud cover, lowering ceilings, or buildups of towering clouds, most generally foretell precipitation and, if he is at all observant of the sky, will make his plans accordingly. After reading Mr. Miller's work, he will now know generally what causes the clouds, and if precipitation falls, what perhaps may have caused it; but his ability to guess picnic weather tomorrow will have been increased very little, if at all.

This is indeed an extremely worthwhile, as well as interesting book. Even though it appears to this reviewer that it fails of its avowed purpose, it is a valuable addition to the literature.

Since the publication of the November, 1952, Journal, the Society has learned with the utmost regret of the following deaths among its members:

ADAMS, R. R., Naval Member

CLUVERIUS, WATT T., Naval Member

CURRIER, CHARLES H., Civil Member

DRAKE, MARCUS M., Civil Member

EVANS, WALTER C., Civil Member

FROBE, RAYMOND WILLIAM, Naval Member

HOXIE, W. W., Civil Member

KORLICK, PAUL J., Associate Member

ROBERTS, HERBERT A., Civil Member

ROBISON, S. S., Honorary Member

SCHULTZE, WILLIAM H., Associate Member

TAYLOR, MONTGOMERY M., Honorary Member

VONASCH, RAYMOND W., Civil Member

WILLIAMSON, EARL C., Associate Member

YATES, RUSSELL E., Naval Member

MEMBERSHIP CHANGES

It is with much pleasure that the following additions to our membership since the publication of the November, 1952, JOURNAL are announced:

NAVAL

Baldwin, William Wayland, Lieutenant, USNR,
Chief Engineer, USS *Ingraham*,
Mail: 41 Pearl St., Essex Junction, Vt.

Bauer, Carl Edward, Lieutenant, USNR, Plant Engineer,
International Silver Co., Florence, Mass.

Benjamin, Lysle I., Lieutenant (j.g.), USCG,
CGC *Ironwood* (WAGL 297),
% Fleet P. O., San Francisco, Calif.

Burgess, Marvin Sylvester, Lieutenant, USNR,
USS *Whitley* (AKA 91),
% Fleet P. O., San Francisco, Calif.

Burpo, Robert S., Jr., Lieut. Commander, USN,
New York Naval Shipyard, Brooklyn, N. Y.,
Mail: 95 Arlo Road, Apt. 28, Staten Island 1, N. Y.

Clark, Lloyd James, Lieut. Commander, USNR,
Asst. Design Officer (Hull) Supship-Insord,
Bethlehem Shipbuilding Co., Quincy, Mass.,
Mail: 121 Larchmont Road, Melrose, Mass.

Davidson, David, Lieutenant, USN,
6430 No. Glenwood Ave., Chicago 26, Ill.

Drehoff, John James, Jr., Lieutenant (j.g.), USNR,
USS *Egret* (AMS 46), % Fleet P. O., New York, N. Y.

Dusinberre, George Merrick, Commander (Ret.), USN,
Professor of Mechanical Engineering, Pennsylvania State College,
State College, Pa.

Estes, Ottis Tillman, Commander, USCG,
U. S. Coast Guard Headquarters,
1300 E St., N. W., Washington, D. C.

Fisher, Thomas N., Lieutenant, (E) USNR,
Naval Supply Dept., Mechanicsburg, Pa.,
Mail: 29 South 27th St., Camp Hill, Pa.

Freeman, Ames Lloyd, Lieutenant, USNR,
5011 East Ocean Boulevard, Long Beach, Calif.

Garay, Paul Nicholas, Lieutenant, USN,
Ship Repair Facility, Navy No. 393,
% Fleet P. O., San Francisco, Calif.

Harrison, William Marcus, Lieutenant, USN,
Bureau of Ships, Code 743, Dept. of the Navy,
Washington 25, D. C.

Hicks, James M., Captain, USN,
Commanding Officer Naval Administrative Unit,
M.I.T., Cambridge 39, Mass.

Knoll, David Walter, Ensign, USN,
USS *Matthews* (AKA 96),
% Fleet P. O., San Francisco, Calif.

Kroeger, Carrol Vincent, Lieutenant, USNR,
2613 Tacoma Ave., Muncie, Ind.

Matheson, James Cobb, Lieutenant, USN,
Riverview Road, New Castle, N. H.

Mende, Robert Graham, Lieutenant (j.g.), USNR,
192 Ashley Ave., Charleston, S. C.

Rakes, Calvin Eugene, Lieutenant (j.g.), USN,
6-4 Garden Lane, Waltham 54, Mass.

Reshke, Arthur Julius, Lieutenant (j.g.), USN,
USS *Shenandoah* (AD 26), % Fleet P. O., New York, N. Y.

Smith, Lewis Fields, Lieutenant (j.g.), USN,
1543 East 31st St., Oakland, Calif.

Smith, Paul Bridges, Lieut. Commander, USN,
21 Citrus, Vallejo, Calif.

Still, Donnell Moody, Sales Engineer, Sperry Gyroscope Co.,
Mail: 259 Schepis Ave., Fairlawn, N. J.

Treadwell, Kenneth Myron, Lieutenant (j.g.), USN,
Box 2033, U. S. Naval Postgraduate School,
Monterey, Calif.

Verge, William E., Rear Admiral, USN (Ret.),
Director of Public Relations,
The Industrial Corporation,
1100 Baltimore Life Bldg., Baltimore 1, Md.

Weaver, George Calvin, Captain, USN,
Long Beach Naval Shipyard, Long Beach, Calif.

Wesson, Robert Walter, Lieutenant, USNR,
Design Engineer, Carbide & Carbon Chemicals Co.,
Mail: 107 Zerkle St., St. Albans, West Va.

CIVIL

Buchi, Dr. Alfred J., Engineer,
% Mr. Ernest G. Huber, 520 Munsey Bldg.,
Washington, D. C.

Capelle, Ernest A., Washington Sales Engineer,
Taylor Instrument Companies, Rochester, N. Y.,
Mail: 8404 Ramsey Ave., Silver Spring, Md.

Cartin, William Joseph, Marine Engineer, Submarine Branch,
Bureau of Ships, Navy Dept.,
Mail: 117 Heather Lane, Lee Blvd. Hts., Falls Church, Va.

Cassarino, Sebastian James, Marine Engineer,
Bureau of Ships, Navy Dept.,
Mail: 2515 14th St., N. W., Washington, D. C.

Dannenbower, Gilbert L., Manager, Swiss American Gear Co.,
Mail: 142 Greenwood Road, Westfield, N. J.

DeWitt, Edward James, President and General Manager,
Wallace Supplies Mfg. Co., Chicago, Ill.
Mail: 1311 Forest Glen Drive, South, Winnetka, Ill.

Griswold, William Rockwell, Rep. for Bureaus of Ordnance and Ships,
Sperry Gyroscope Co.,
Mail: 3 Harrow Road, Franklin Square, L. I., N. Y.

Gudgel, John William, Vice President,
Kewanee-Ross Corp., Buffalo, N. Y.,
Mail: 71 University Ave., Buffalo, N. Y.

Hershey, Mayo Dyer, Mechanical Engineer,
U. S. Naval Experiment Station, Annapolis, Md.

Kilpatrick, James Nelson, Chief Engineer, Ships Supply Depot,
Naval Supply Center, Norfolk, Va.,
Mail: 200 W. Bay Ave., Norfolk 3, Va.

King, Omar R., Yard Manager, Bath Iron Works Corp.,
Mail: 1282 High St., Bath, Maine

Korvin-Kroukovoky, B. V., Research Professor in Fluid Dynamics,
Experimental Towing Tank, Stevens Institute of Technology, Hoboken, N. J.,
Mail: Montebello Road, Suffren, N. Y.

Lippincott, S. S., Flexitallic Packing Co.,
8th & Bailey Sts., Camden, N. J.

Matson, James Hale, Federal Government, General Engineer,
Aviation Supply Office,
Mail: 7724-A Lucretia Mott, Elkins Park, Pa.

Olberding, Vincent Paul, Control Instruments Co.,
67 35th St., Brooklyn, N. Y.

Skidmore, Ashley G., Bureau of Ships, Navy Dept.,
Mail: 1618 Webster St.. N. W., Washington, D. C.

Spoerr, Frank F., Sales Manager, Marine Dept.,
Carrier Corp., 385 Madison Ave., New York, N. Y.

Swaine, Clifford P., Vice President and Chief Engineer,
John C. Allen, Inc., 131 State St., Boston, Mass.

Tashjian, David R., Manager, Ship and Shore Engineering,
Electronics Division, Westinghouse Electric Corp.,
Mail: 402 Oak Forest Ave., Baltimore 28, Md.

Voss, Jack Henning, Production Engineer, Bureau of Ships, Navy Dept.,
Mail: 7056 No. Morun Ave., Chicago 30, Ill.

Wells, John W., Naval Architect, Coast Guard,
Mail: 508 No. West St., Falls Church, Va.

Young, William Charles, Special Representative, Nordberg Mfg. Co.,
Mail: 7900 Sleaford Place, Bethesda, Md.

ASSOCIATE

Bauer, George Henry, Sales Manager,
Foster Engineering Co., 835 Lehigh Ave., Union, N. J.

Donnini, Rocco, Dr. Ing. Chief Technical Dept.,
Compagnia Internazionale, Di. Genova,
Mail: Via Assarotti 54, Genova, Italy

Flaherty, Leo Michael, Jr.,
Contract Representative, Control Instrument Co., Inc.,
Mail: 909 Belvedere Blvd., Silver Spring, Md.

Marguery, Jorge Alfredo, Lieut. Commander, Argentine Navy,
Acevedo 859, Lomas De Zamoto, Argentine Republic

Mead, Stanley E., Instrument Designer, Sig-Trans, Inc.,
Mail: 3 Locust St., Amesbury, Mass.

Saddler, Ivan Roy, 1st Lieutenant, Signal Corps, USA,
Field Representative, RCA Victor,
Mail: 501 N. Oakland St., Arlington, Va.

Schoen, Rudolph 3d, Marine Engineer, Combustion Engineer, Superheater, Inc.,
3784 Tenth Ave., New York 34, N. Y.

Wiener, Jesse L., Vice President, Juniper Elbow Co., Inc.,
Mail: 7215 Metropolitan Ave., Middle Village 79, N. Y.

TRANSFERRED FROM ASSOCIATE TO LIFE MEMBERSHIP

Halpern, Benjamin

RESIGNED

NAVAL

Daniels, M. R.
DeSoboll, F. Stephen
Faughn, James L.
Flanders, Warren B.
Heiner, John N.
Jenkins, William H.
Kane, Lail H.
McLain, Wm. C.
Molloy, George Pryor
Neubert, Charles V.
Poindexter, Gale A.
Stevens, Robert H.
Stram, LeRoy, Jr.
Thompson, Beriah

CIVIL

Bankwitz, F. E.
Dennison, Boyd C., Jr.
Echevarris, Albert E.
Gill, Charles F.
Klemgard, Edwin N.
McGready, L. S.
McKinstry, W. S.
Morrison, John F.
Rooney, Walter Richard
Schreiber, A. F.
Wilbur, Ralph S.
Winterer, Frank John
Winterer, Herman Francis
Winterer, Joseph H.
Wood, Corlan E.
Wright, Justice Wesley

ASSOCIATE

Boohj, Max Lorence
Everhardt, Ren
Mikolic, Michael
Whitten, Leslie
Wylie, J. C.

DROPPED FROM ROLLS

In accordance with the requirement of the By-Laws, it became necessary on 31 December, 1952, to drop from our rolls 133 members who were two years in arrears for dues.

ASSOCIATION NOTES

ORIGINAL ARTICLES

The editor of the JOURNAL is most anxious to obtain manuscripts of original articles on subjects of interest to naval engineers. Any manuscript accepted for publication becomes the property of the Society which copyrights it upon publication. Authors are paid from $40.00 to $150.00 depending upon length, interest and professional value.

The rules for manuscripts are as simple as we can make them.

1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

5. Photographs may be negatives, but glossy prints are acceptable.

6. Include on a separate page a short biographical sketch(es) of the author(s). 50 to 100 words for each author is desired.

Manuscripts should be mailed addressed to:

Secretary-Treasurer
American Society of Naval Engineers
605 F St., N. W.
Washington 4, D. C.

Manuscripts accepted will not be returned unless specifically requested by the author. If returned, they will be in the condition which has resulted from the work of the printer and the engraver. Immediately following publication, the author is furnished 10 reprint copies of his article free of charge. Additional copies may be purchased from the Society if the request is received 30 days prior to the publication date which is the 25th of the issue month. Estimate of cost of additional reprints, which will vary with the nature of the article and the number of copies ordered, will be furnished on request as soon as possible after the article is set up.

Manuscripts not accepted will be returned, postpaid, by the Society.

Manuscripts which are accepted will be published in the earliest JOURNAL which has not yet been closed (60 days before publication) and for which insufficient material is already on hand.

SUBJECT MATTER AND AUTHORS

To assist the editor in programming future issues, the help of all members is solicited. To make it easy, the last page in this issue is readily detachable as you will find. This page has blanks for two entries.

(a) What subject would you, as a member, like to see covered by an article in the JOURNAL.

and

(b) Who do you consider best qualified to prepare such an article authoritatively, and what is his address (if you know).

Any of these forms which are filled in and mailed to the Society will be received with thanks and the editor will follow up to get the suggested articles prepared.

PHOTOGRAPHS

Photographs of current or historical interest to readers of the JOURNAL are desired. Any which are accepted by the Society will be purchased by the Society at a standard price of $5.00 each. Such purchase *will not* include any copyright by the Society, but the contributor must hold the Society free from any charge of violation of any previous copyright.

NOTICE OF DEATHS

The Society has no satisfactory machinery for obtaining notice of deaths of members. It is particularly desired that we receive such notice upon the death of any past officer, past member of the Council or member of more than twenty years' standing with photographs and short obituaries. It will be appreciated greatly if any member who learns of the death of a member will advise the Secretary-Treasurer.

SOCIETY LAPEL BUTTONS

Shown below is an illustration of the lapel button of the Society. It is believed that it will be conceded that this is a very fine dignified insignia. It is one-half inch in diameter.

The oak leaves and lettering are red on a gold background.

It is available to all members at fifty cents (50c) each.

Permission is granted to reprint any original article contained herein if the following conditions are met:

a) Credit is given to the JOURNAL with reference to the issue.

b) Credit is given to the author.

c) If the author is a military officer or a civilian employe of the Department of Defense, the following note shall be carried:

"The views expressed herein are the personal ones of the author and are not necessarily the official views of the Department of Defense or of a Military Department."

THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Financial Statements, 1952

Statement of Income and Expenditures

Income

Publication:		
Dues	$21,933.75	
Advertisements	7,675.00	
Sales (General)	772.35	
Sales (Buttons)	15.50	
Subscriptions	17,193.00	$47,589.60
Interest on Investments		1,525.00
Banquet, 1952		1,171.16
		$50,285.76

Expenditures

Publication:		
Printing	$29,213.31	
Engraving	2,001.78	
Manuscript	3,110.00	
Postage	518.14	
Commission	208.65	
Exchange	.80	
	$35,052.68	
Salaries	8,400.00	
General Expense	1,978.49	
Current Profit and Loss	2,186.99	47,618.16
NET GAIN		$ 2,667.60

THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

FINANCIAL STATEMENTS, 1952

BALANCE STATEMENT

Assets December 31, 1952:			
Cash		$ 5,329.39	
Petty Cash		50.00	
Accounts Receivable:			
Advertisements	$ 2,663.22		
Dues	1,458.25		
Sales	263.46		
Subscriptions	420.00	4,804.93	
Investments:			
U.S. Defense Bonds (Series G)	58,000.00		
Washington Gas Light Co. Bonds	997.50	58,997.50	
Furniture		122.58	
Manuscript Paid in Advance		1,200.00	$70,504.40
Liabilities (Accounting Only):			
Advertisements Paid in Advance	$ 112.50		
Dues Paid in Advance	421.73		
Subscriptions Paid in Advance	9,029.50		9,563.73
Total Net Assets December 31, 1952			$60,940.67
Total Assets January 1, 1952			58,273.07
NET GAIN			$ 2,667.60

Respectfully submitted,

/s/ J. E. HAMILTON,

Secretary-Treasurer

Audited and Found Correct:

/s/ MR. CHARLES G. COOPER
/s/ MR. DOUGLAS GIBSON
/s/ MR. WARREN T. JOHNSON
} Audit Committee

DEFENDERS OF FREEDOM

Our United States Navy submarines with their superb crews will help protect our shores and our shipping from possible enemy undersea craft. Supreme dependability and instant response are required of engines and crews. The United States Navy has installed General Motors engines with Diesel-Electric Drive in submarines of this new "K" class.

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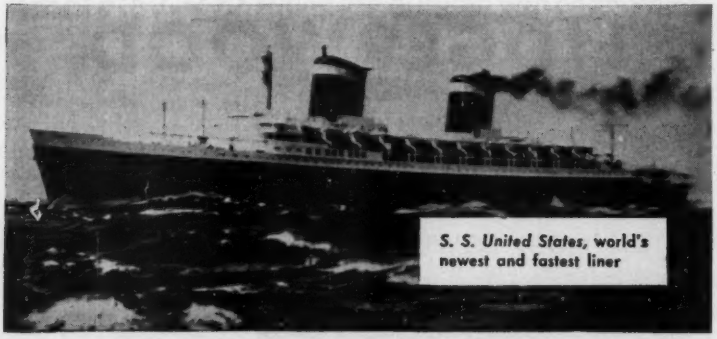

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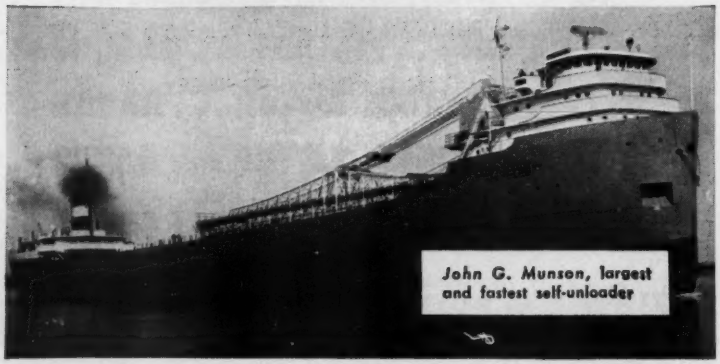

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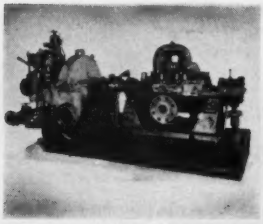

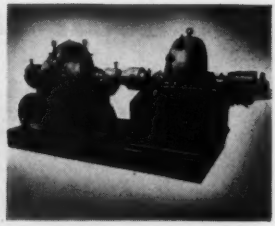

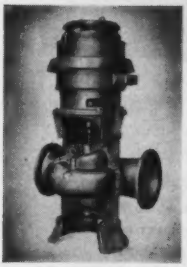
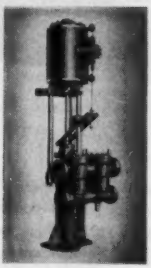
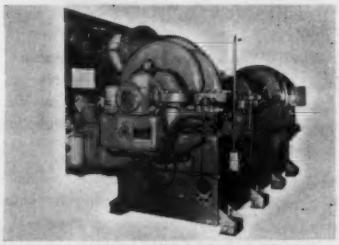
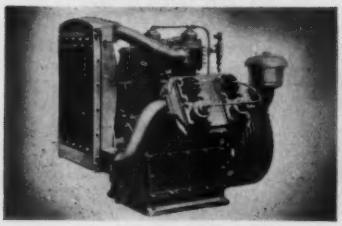

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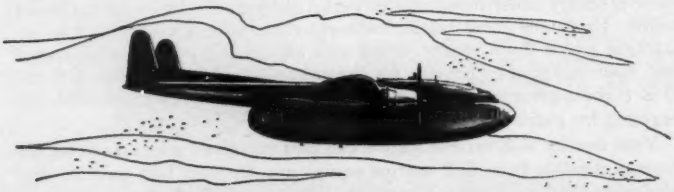

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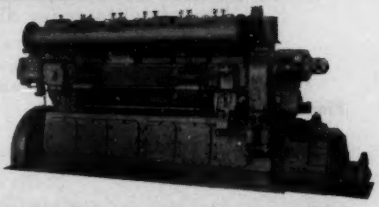

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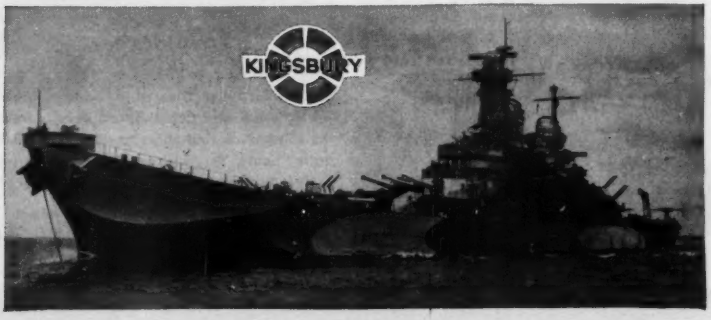

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